SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-86/9

Interim Report

ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL USE OF MAINTENANCE FUNDS: AN ESTIMATION OF SERVICE LIFE AND COST OF ROUTINE MAINTENANCE ACTIVITIES

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Kumares C. Sinha
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PURDUE UNIVERSITY

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Purdue University

in cooperation with the

Indiana Department of Highways

and the

U.S. Department of Transportation
Federal Highway Administration

Purdue University
West Lafayette, Indiana
August 27, 1986
Revised April 3, 1987

Interim Report

Executive Summary

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TO: H. L. Michael, Director
Joint Highway Research Project

August 27, 1986
Revised April 3, 1987
Project No: C-36-63K

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

File: 9-7-11

Attached is the Interim Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds: An Estimation of Service Life and Cost of Routine Maintenance Activities." This interim report covers the Tasks A, B and D dealing with the estimation of service life and cost of routine maintenance activities. The study was conducted by Kieran Feighan under the direction of Profs. Kumares C. Sinha and Thomas D. White.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

K. C. Sinha
Research Engineer

KCS/rrp

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16. Abstract

This report presents the findings of the research work that was undertaken to evaluate the service life and cost of routine maintenance activities. The estimates include various pavement, shoulder and drainage - related activities. The procedure was based on a statistical random survey of unit foremen using a questionnaire approach. These estimates will be used to identify cost-effective treatments at project and network level.

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Introduction

Interest in Pavement Maintenance Management has grown steadily over the last ten years or so. This interest has been largely motivated by a desire to obtain a greater degree of control and standardization of approach in order to achieve ultimately a better return per dollar invested in the construction and maintenance of pavements. However, most of the research that has been undertaken to date has been in the area of major maintenance. Consequently, there is limited published information on techniques and data concerning routine maintenance activities and management. The awareness of routine maintenance as a major consumer of limited highway funds is the motivating factor for the research being conducted at Purdue University in developing a routine maintenance management program for the Indiana Department of Highways (IDOH). This report describes research into service life and costs of some of the routine maintenance activities in Indiana as these values were deemed to be essential inputs for such a program.

Background

There is currently a Maintenance Management System (1) operating successfully at the network level in Indiana. The major features of the current system that are relevant to this research are [1] The Field Operators Manual (2) and [2] Crew Day Cards. The Field Operators Manual basically consists of a set of performance standards for each designated maintenance activity. Each

activity is identified by a number. The performance standard gives a description of the activity in question and a recommended maintenance procedure as well as a standard crew size, equipment complement and a range of expected average daily production.

The Crew Day Cards provide a means of authorizing work to be done and recording work completed. One crew day card is given to each crew leader every morning with details of the nature and location of the work as well as assignment of employees and equipment. At the end of the day, the crew leader fills in the number of accomplishment units achieved that day as well as the manhours worked and the equipment and materials used. Thus it is possible to subsequently determine average manhours, material usage and other information, per production unit.

This management system has been in operation in Indiana since 1975 and a large amount of data has been accumulated over this time. The system has produced a relatively high degree of uniformity in maintenance procedures.

Need For Data

A variety of treatment alternatives exist for different types and levels of pavement and shoulder distress within the field of routine maintenance. All of these treatments will be effective to one degree or another, but a need exists to evaluate which methods produce the best solution to a given problem. In order to determine such an optimal solution, regardless of the nature of the deficiency, it is essential that two parameters be

known; the service life and the cost of each of the alternatives.

The following uses have been put forward as justification for research into the estimation of expected service life and costs(3,4).

1. To estimate and allocate funds available.

2. To identify the most cost-effective solutions.

3. To monitor if change in work practices or materials significantly increases service life and to evaluate whether or not such changes are cost-effective.

4. To identify locations which consistently underscore the expected life of a given treatment.

5. To justify a change in emphasis at the network level, e.g. advocating sealing (preventive maintenance) over patching (corrective maintenance).

6. To anticipate when necessary expenditure will re-occur.

7. To co-ordinate with PMS and other management systems in working out the most cost-effective "holding" action until major rehabilitation or reconstruction can take place.

Definition of Parameters Estimated

Having established the need for the data, the next step is to determine how best to obtain the necessary information. A review of routine maintenance activities conducted by IDOH

indicated that not all activities were of equal importance. Consequently, in the initial work a number of activities were selected from the general areas of pavement, shoulder and highway drainage. The criteria applied in selecting the activities were [1] annual expenditure per activity and [2] annual volume of work performed per activity.

Service Life Estimates; The expected service life of any treatment may vary with the degree of deficiency of any particular distress type as well as from distress type to distress type. There are also unique influences peculiar to each general category of pavements, shoulders and drainage.

A distinction between actual and effective service life must be made as it is crucial to understanding the uses to which the data accumulated can be put. An actual service life of a given treatment is regarded as the time elapsed from when the treatment is applied to the point in time when its condition falls below a prescribed, measurable value. In the present research, rather than the actual service life of a treatment, an estimate of the effective service life was made to represent the time elapsed from when the treatment is applied until the time when, in the opinion of the field personnel, it needs to be replaced.

In the establishment of a maintenance management program, what is of ultimate concern is the amount of money spent on any given activity and the way that available monies can be spent to produce the maximum good. In the area of routine maintenance,

the operation and implementation of available funds is basically carried out by field personnel. In the IDOH organization, geographic areas of responsibility are broken down into districts, subdistricts and units. On a road mileage basis, a unit averages approximately 140 miles. The unit foremen are responsible for deciding in the first instance when and where work needs to be carried out. Hence, it is relevant and is finally useful, to obtain an estimate of how long a treatment lasts based on the opinion of the unit foreman rather than in actuality.

This approach to service life estimation is not new or unique. Ontario has already carried out such a survey as part of its Routine Maintenance Program (RMP) and has incorporated the results, both service life estimates and costs, into its overall RMP system(5).

There is no doubt that a need exists for research to be carried out into actual service lives. However, as such specific information becomes available in the future, the appropriate service life functions can be inserted in the proposed Routine Maintenance Management Program.

Cost Information; A large amount of research has been undertaken in recent years at Purdue into the overall and specific costs of routine maintenance activities in Indiana (6,7). As a consequence of this prior research, it was possible to obtain a unit cost per production unit for each activity. In Table 1, a summary of the unit cost data is presented for each of the activi-

ties considered in the study. It was previously mentioned that Crew Day Cards were required to be filled in each day and that daily accomplishment was one of the values listed. Thus, maintenance personnel are familiar with the concept of production units and with the variation in production caused by changing roadway or climatic conditions. It is also believed that using production units as an indirect measure of cost yields greater potential for transferability of results for comparison purposes.

Structure of Questionnaire

A questionnaire was used to acquire service life estimates. This questionnaire is laid out in a tabular/matrix type format. There are three categories of condition for each activity which generally conform to the overall descriptors of poor, fair and good although there is some variation in definition depending on the particular activity in question.

The condition input is further sub-divided into cells consisting of three components. These roughly correspond to minimum, average and maximum. All refer to service life estimates currently given by the unit foremen with available manpower, equipment, materials, and so on. A decision was made to look for minimum and maximum values as well as an average value because it was felt that the average value alone could be misleading in terms of the overall range of performance.

Minimum service life values are not intended to be the single worst case in the experience of the unit foreman but rather

an indication of what is considered to be a realistic, poor service life value. Similarly, the maximum value is considered to reflect a generally high service life value as opposed to the longest service life history known to the unit foreman.

In a survey such as this, a decision must be made as to the detail and accuracy of results which can be reasonably expected. A necessary tradeoff must be made between amount of data acquired and the consequent error induced in the respondent's estimates through boredom, desire to complete the survey rapidly, and so on. It is believed that the questionnaire used struck a reasonable compromise in this regard.

Description of Survey Methodology

Implementation of the survey questionnaire involved consideration of where and how many interviews should be conducted. The State is divided into six administrative districts, each of which is comprised of a number of subdistricts. To interview personnel in all 37 of the subdistricts would have been extremely costly, time-consuming and difficult to arrange.

A decision was made to choose subdistricts to take part in the survey by a process of stratified random sampling. In using this technique two subdistricts were selected at random from each district. When the individual strata contain relatively homogenous elements, the variability for a given stratified random sample will be less than in a simple random sample of the same size, i.e. the stratified sample is more efficient (8).

Homogenity for each stratum is considered reasonable in that each subdistrict within a district is subject to much the same climatic and topographic conditions and usually has the same source of maintenance materials and equipment. In addition, meetings of all subdistrict supervisors and general foremen occur on a regular basis and consequently repair strategies and methods would be expected to be fairly consistent.

Discernible patterns in the service life estimates for a number of the activities were anticipated due to the large difference in climate and topography between Northern and Southern Indiana. The use of stratified sampling made it possible to examine and identify such patterns as well as estimate the overall population characteristics. From the point of view of feasibility, the fact that two subdistricts from each district were chosen meant that it was generally possible to interview in two subdistricts each day, thus reducing time and travel costs. The entire survey was carried out in a two-week period at the end of June, 1985.

Generally, at each subdistrict office a meeting was held with the general foreman and two unit foremen. Throughout the state a total of 33 maintenance personnel were interviewed. A personal interview approach was utilized to obtain data as opposed to mailed questionnaire to both reduce ambiguous responses and increase the response rate. It should be noted that the field personnel were extremely co-operative and knowledgeable in every instance. Care was taken to avoid asking

leading questions and generally very little prompting was required to get numerical estimates with accompanying justification for the values given.

Analysis of Results

The results of the service life estimation survey are summarized in Tables 2 through 4 for pavement related activities and Tables 5 and 6 for shoulder and drainage related activities. A discussion of individual activities is presented below.

Shallow Patching

There are four sub-divisions within this activity corresponding to the different possible materials used in patching. They are hot mix, cold mix, winter or fibre mix and fibre mix heated in a Portapatcher. Each of these materials was treated as a separate subject of interest with service life and accomplishments being recorded for all four types.

The effective service life of a patch was taken to be the time elapsed until more work was necessitated at the location where the patch was placed. This approach was taken as it was pointed out by the maintenance personnel that, although the material in the patch itself may remain in place for a considerable length of time, cracking and break-up at the edges of the patch may require early repair with additional patching. Patching accomplishments per day (a.p.d.) vary in an expected way, decreasing as the roadway condition improves and decreasing as

the service life increases. This pattern is consistent for all four types of shallow patching.

Patching a.p.d. decreases with improving roadway condition simply because there is less severe distress at any one location and distressed locations are further apart on a road in good condition as opposed to a road in poor condition. There are two reasons why the service life and a.p.d. vary inversely for a given road condition. Firstly, a location which yields a high a.p.d. generally exhibits a large amount of distress. The source of this distress may be poor drainage, heavy traffic volumes etc., and undoubtedly this source will cause failure around the newly- patched surface. Thus there is no cause-and-effect relationship between service life and a.p.d. per se here; both simply reflect the effect of the distress source. Secondly, if more care and thoroughness is practised in placing the patch mix, the daily accomplishment will go down but this care will be reflected in an increased effective service life. These two factors combined, explain the difference in a.p.d. between minimum, average and maximum for any given roadway condition.

<u>Hot Mix Patch</u>; Hot mix patching has consistently the highest estimate of effective service life. There are a number of reasons why this is so. Firstly, the material is usually of superior quality and therefore is easier to place and compact than the other three types of patching material. Also, hot mix is generally only available between April and October as plant production is limited to these months. Consequently, the climatic

and road-base conditions are usually favorable for placement of the patch which naturally leads to greater longevity.

It was generally considered that a hot mix patch placed on a good road should function effectively throughout the service life of the road surface. This service life, was taken to be 60 months for the purposes of calculation.

Cold Mix Patch; Cold mix patching material was considered by all personnel surveyed to be the poorest performer of the four types of patch material. The results in Table 2 indicates that most service life estimates were given in days rather than months. The primary factor for this low service life is that the conditions under which the cold mix is placed make it difficult for the patch to hold. Cold mix is generally used in winter when no hot mix is available and consequently is placed in poor weather conditions that often includes a wet road-base.

The combination of water and traffic loads can lead to early patch failure and if snow ploughs are being used the patches can be removed over night. Additionally, cold patch material as used is not adequate, being prone to shoving.

Winter Mix Patch; Winter mix patching material is essentially a cold mix with fibres added to produce greater stability and resistance to shoving and is used under the same conditions as cold mix. Almost all personnel interviewed believed that the winter patch material was significantly better than cold mix in its ability to stay in position and this opinion is reflected in

the service life estimates obtained.

Winter Mix Patch Using Portapatcher; A Portapatcher provides the facility to heat patching material. Heating patching material improves its workability for placement and compaction. Patches made with material heated in a Portapatcher were estimated to have a longer service life than patches made with cold mix. Two of the four northern subdistricts of IDOH expressed the opinion that the performance of winter mix heated in a portapatcher was as good as patches made with hot mix.

In locations where flexibility and elasticity are important, e.g. on bridge decks, the heated fibre mix patch appeared to perform better than a hot mix patch. One drawback to using the portapatcher is that a larger crewsize is required.

Premix Leveling

Premix leveling or wedging involves placement of bituminous mixtures to correct depressions and rutting. Several subdistricts indicated that this activity is now primarily carried out by contract rather than by IDOH personnel. However, most subdistricts had sufficient experience to estimate service life and daily accomplishments.

The estimates follow an expected pattern for similar reasons to those mentioned in the discussion on patching. The primary reason given for early failure of wedging was the roadway surface not being tacked properly prior to application of the bituminous

mixture.

In the case of, premix leveling, a distinction was frequently made between the service life when material was placed using a grader as opposed to using a paving machine. Also, the opinion prevailed that the paver produces a more uniform, better-riding and longer-lasting surface.

Full Width Shoulder Seal

Shoulder sealing specifically involves seal coating of an existing paved shoulder. When the paved shoulder condition is poor, the general consensus of opinion was that a shoulder seal was not an appropriate treatment as no additional structural support is provided. The appropriate treatment of a paved shoulder in poor condition was deemed to be rebuilding.

Survey results indicate that the service life and a.p.d. vary directly in shoulder sealing. The explanation for this relation is that the unit of accomplishment is foot-miles. Thus, a shoulder at the lower end of the fair shoulder range will require more work (and hence less miles covered) and yet will break up faster than a shoulder at the upper end of the range. Consequently, as in previous relations, the source of the deficiency establishes the relationship between accomplishments and service life. The major factor that influences the a.p.d. obtained is the width of the shoulder to be sealed as the unit of accomplishment is foot-miles. Obviously a much higher a.p.d. will be obtainable on a 10 foot shoulder than on a 3 foot one.

Seal Coating

There are two sub-divisions which fall under the general headings of seal coating. These are chip seal treatments and sand seal treatments. As the name implies, they differ primarily in the aggregate coating used in the seal coating operation.

Chip Seal; Chip Sealing consists of coating full width roadway sections with hot bituminous material and covering with #11 or #12 stone. One factor that can influence the service life obtained is the type of stone used in the surfacing operation; limestone chips were believed to be preferable to pea gravel.

The service life and a.p.d. pattern of seal coating is similar to that seen in the discussion of Full Width Shoulder Seal. The major factor governing the a.p.d. was the haulage distance for bituminous material and aggregate rather than the roadway surface itself.

Sand Seal; The cover aggregate in sand seal is, as implied, sand rather than stone. From the survey a total of 5 subdistricts believed they had sufficient experience to estimate sand seal values, although a number of the other subdistricts have begun to utilize this activity in the last 2 to 3 years. An opinion in general was that the sand seal was not effective on a poor roadway condition. On such a surface, the sand seal would not prevent further deterioration or correct cracking for any appreciable length of time. On roads in fair or good condition, the consensus of opinion was that a sand seal is effective in sealing

cracks and will contribute substantially to the longevity of the road life. One subdistrict reported that the sand seal was effective when placed over a "fatted" surface, i.e. a pavement surface with flushed asphalt whereas the chip seal was better suited to dried-out pavements. The same trends in service life and a.p.d. observed in the shoulder seal activity are again evident here, namely a direct relationship between daily accomplishment and service life.

Sealing Longitudinal Cracks and Joints

Sealing longitudinal cracks and joints is accomplished by cleaning the cracks and joints and then filling them with liquid bituminous sealant. The usual method of crack and joint cleaning is to use a stream of compressed air to blow out the accumulated debris. An alternative method of cleaning the cracks and joints is to use a crack router attached to a tractor but this operation is not considered here.

An examination of Tables 2, 3 and 4 shows that there is not a large difference between maximum and minimum service life estimates of crack and joint sealing for any given roadway condition. However, the a.p.d. estimates for sealing do vary substantially as the roadway condition changes. This is to be expected as the accomplishment unit is in linear miles and less sealing is required on a road in good condition compared to a road in poor condition.

Sealing Cracks

The purpose of this activity is to clean and seal cracks in

both bituminous and concrete roadways. An examination of the values obtained shows a marked difference between maximum and minimum service life for each roadway condition in contrast with the previous activity.

A definite relation exists between a.p.d. and the roadway condition which is to be expected as a workman will cover fewer lane miles as the amount of cracking increases.

Spot Repair of Unpaved Shoulders

Spot repair involves the repair of small areas of unpaved shoulders with addition of aggregate and reshaping. Little significant difference exists overall in service life estimates given by various subdistricts except for the minimum values of service life in the southern region of the state. An explanation of this lower value may be explained by the topography in Southern Indiana which is hilly.

A strong influence on the service life of unpaved shoulder spot repair was believed to be rainfall in combination with high gradients. These factors, reinforced by traffic encroachment onto the shoulder at curves, provided the lowest estimate of service life. Service life and a.p.d. vary inversely in this activity because the accomplishment unit is tons of aggregate and the worst locations require more aggregate.

Blading Shoulders

Blading shoulders involves the redistribution of material

and reshaping of unpaved shoulders. As the daily accomplishment unit is in shoulder miles, there is a direct relationship between service life and a.p.d. with the poorest locations yielding the lowest service life and lowest a.p.d. The preferred equipment for this activity was a dump truck with scraper or underblade attached.

Clipping Shoulders

In shoulder clipping excess growth is removed from unpaved shoulders to restore adequate shoulder drainage. For a given shoulder condition, the southern subdistricts' estimates of service life are significantly under the overall average while the northern subdistricts' estimates of service life are significantly above the overall average. The milder climate in Southern Indiana which encourages vegetation growth may explain the difference.

A number of subdistricts distinguished between the a.p.d. using a frontend loader and what was variously described as a dirt loader, belt loader or travel loader. The latter type of loader significantly increased the a.p.d. Factors which influence the a.p.d. include the amount of sand to be cut and loaded and the haulage distance to a disposal site.

Recondition Unpaved Shoulders

Unpaved shoulder reconditioning involves addition of aggre-

gate and reshaping of unpaved shoulders for continuous sections of shoulder as opposed to spot repair which is carried out at isolated spots. None of the four southern subdistricts sampled had sufficient experience to estimate service life or a.p.d. However, in comparing service life and a.p.d., the central region was substantially lower than the northern region. A possible explanation to this difference is that the northern subdistricts tend to seal or oil the rebuilt shoulder in the same year that it is rebuilt which should lead to a longer service life.

An examination of the results shows that in general there was little variation in the service life or a.p.d. for a given shoulder condition. The main variable influencing accomplishment was generally felt to be the aggregate haulage distance.

Clean And Reshape Ditches

Cleaning and reshaping ditches comprises the excavation of dirt and debris from roadside ditches using a gradall which restores the ditch efficiency for adequate drainage. Geography plays a major role in the estimates of both service life and a.p.d. The central and northern subdistricts did not vary excessively in their estimates but the southern subdistricts were much lower in estimates of both service life and a.p.d. In fact, even within the southern region the subdistricts furthest south were significantly lower in their estimation.

The above results indicate topography and soil conditions play an important role in the rapidity and extent of ditch

blockage; in areas with steep hills, heavy rainfall and poor soil conditions, the effective service life is low. For the same reason, the a.p.d., measured in linear feet of ditch, is also low in such areas. Another factor that influences a.p.d. obtained is the distance necessary to haul material removed from the ditch for disposal. An interesting point that was often repeated in discussion with the maintenance personnel was that the daily production can be very misleading. In a ditch that is badly clogged with debris, it may be necessary to make two or three passes with the excavator to restore an adequate cross-section. However, this extra work does not show up in the daily record. This is the basic reason why an examination of Tables 4 and 5 shows such a large variation in a.p.d. for ditch condition.

Motor Patrol Ditching

Motor patrol ditching, as the name implies, involves cleaning of ditches using a motor patrol rather than a gradall. There was much discussion as to the merits and de-merits of one versus the other. In one southern subdistrict, motor patrol ditching is not carried out at all because of the difficultly of operating such equipment on the hilly terrain with heavily blocked ditches. Other limitations on using motor patrols for cleaning ditches include difficulty of operation in wet weather and in areas of claying soils with steep ditches. Conditions favorable to motor patrol ditching include operation in dry weather and in areas with sandy soil and on flat, wide ditches. The consensus of opinion was also that the use of the gradall in cleaning and

reshaping produces a better, more rounded and longer-lasting ditch cross-section than the motor patrol. A comparison of the a.p.d. shows that motor patrol ditching, measured in ditch miles, has a higher production rate than gradall ditching which is measured in feet. The principal explanation for this is that motor patrol ditching is limited to wide areas where few obstructions are present. The main factor that governs the a.p.d. attained is the distance required to haul the debris from the ditch to a designated dump site.

Conclusions

The overall goal of this research is to further evolve a functioning system for Routine Maintenance Management in Indiana. Results reported in this report provide a first, meaningful estimate of service life for a major portion of the routine maintenance activities engaged in by the IDOH. Drawing on records and prior research, both a.p.d. and costs for the various activities are tabulated. With maintenance activity service life, a.p.d. and cost, the basic information is available to establish the framework of a maintenance management system that will address optimal allocation of maintenance resources. Specifically, the data reported here will give initial estimates for parameters that are necessary to make a management system possible. Further research is being conducted in this area that will, over a period of time, provide more definitive functional relations for maintenance activity service life. In the meantime, the information generated in the survey can furnish a reasonable set of input data for the optimization of maintenance decisions.

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Table 1
Production Units and Costs

ACTIVITY	PRODUCTION UNIT	TOTAL COST PER PROD. UNIT
Shallow Patching	Tons of Aggregate	$114.17
Premix Levelling	Tons of Premix	$41.46
Full Width Shoulder Seal	Foot Miles	$177.50
Seal Coating	Lane Miles	$1352.60
Long. Joint And Crack Sealing	Lineal Miles	$108.50
Crack Sealing	Lane Miles	$290.00
Spot Repair Of Unpaved Shoulders	Tons of Aggregate	$13.64
Blading Shoulders	Shoulder Miles	$13.73
Clipping Shoulders	Shoulder Miles	$205.50
Reconditioning Unpaved Shoulders	Shoulder Miles	$885.60
Clean and Reshape Ditches	Linear Feet of Ditch	$0.61
Motor Patrol Ditching	Ditch Miles	$377.80

Table 2
Service Life and Daily Accomplishments
Roadway Condition; POOR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=2.8 APD =7.7	S.L.=8.5 APD =7.2	S.L.=12.5 APD =6.7
Shallow Patching Cold Mix	S.L.=0.2 APD =8.9	S.L.=0.3 APD =7.1	S.L.=0.7 APD =5.5
Shallow Patching Winter Mix	S.L.=1.0 APD =8.0	S.L.=3.7 APD =6.7	S.L.=3.8 APD =5.4
Shallow Patching Portapatcher	S.L.=1.3 APD =6.5	S.L.=5.3 APD =5.4	S.L.=7.3 APD =4.3
Premix Levelling (Wedging)	S.L.=17.1 APD =151	S.L.=24.9 APD =120	S.L.=30.9 APD =88
Seal Coat Chip Seal	S.L.=24.6 APD =5.0	S.L.=26.4 APD =6.3	S.L.=32.4 APD =7.8
Seal Coat Sand Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Sealing Long. Cracks & Joints	S.L.=17.7 APD =5.9	S.L.=22.5 APD =6.3	S.L.=26.2 APD =6.7
Sealing Cracks	S.L.=8.2 APD =1.2	S.L.=13.1 APD =1.5	S.L.=17.4 APD =1.8

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

Table 3
Service Life and Daily Accomplishments
Roadway Condition; FAIR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=9.9 APD =4.4	S.L.=17.2 APD =4.2	S.L.=23.7 APD =4.2
Shallow Patching Cold Mix	S.L.=0.2 APD =4.7	S.L.=0.6 APD =3.9	S.L.=1.0 APD =3.3
Shallow Patching Winter Mix	S.L.=3.1 APD =4.6	S.L.=5.0 APD =4.0	S.L.=5.9 APD =3.3
Shallow Patching Portapatcher	S.L.=6.6 APD =4.8	S.L.=8.9 APD =3.8	S.L.=11.6 APD =2.8
Premix Levelling (Wedging)	S.L.=29.1 APD =105	S.L.=34.3 APD =89	S.L.=41.1 APD =69
Seal Coat Chip Seal	S.L.=31.8 APD =5.5	S.L.=37.4 APD =6.8	S.L.=45.6 APD =8.5
Seal Coat Sand Seal	S.L.=14.4 APD =6.2	S.L.=15.6 APD =8.2	S.L.=20.4 APD =10.8
Sealing Long. Cracks & Joints	S.L.=25.6 APD =8.0	S.L.=29.5 APD =8.4	S.L.=33.3 APD =9.1
Sealing Cracks	S.L.=13.6 APD =2.8	S.L.=19.9 APD =3.0	S.L.=24.5 APD =3.1

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

Table 4
Service Life and Daily Accomplishments
Roadway Condition; GOOD

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Shallow Patching Hot Mix	S.L.=36.0 APD =3.0	S.L.=53.4 APD =2.8	S.L.=54.2 APD =2.5
Shallow Patching Cold Mix	S.L.=0.3 APD =3.2	S.L.=0.7 APD =2.6	S.L.=1.2 APD =2.2
Shallow Patching Winter Mix	S.L.=3.3 APD =3.3	S.L.=5.8 APD =2.7	S.L.=6.8 APD =2.4
Shallow Patching Portapatcher	S.L.=14.7 APD =3.1	S.L.=23.1 APD =2.7	S.L.=24.1 APD =2.3
Premix Levelling (Wedging)	S.L.=36.0 APD =65.7	S.L.=47.1 APD =55	S.L.=49.7 APD =48
Seal Coat Chip Seal	S.L.=37.8 APD =6.2	S.L.=48.0 APD =7.5	S.L.=55.2 APD =9.1
Seal Coat Sand Seal	S.L.=19.2 APD =6.2	S.L.=21.6 APD =8.2	S.L.=28.8 APD =10.8
Sealing Long. Cracks & Joints	S.L.=31.6 APD =9.8	S.L.=34.9 APD =10.2	S.L.=38.2 APD =10.9
Sealing Cracks	S.L.=20.7 APD =4.1	S.L.=26.5 APD =4.5	S.L.=31.6 APD =4.9

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

Table 5
Service Life and Daily Accomplishments
Shoulder/Ditch Condition; POOR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=0 APD =0	S.L.=0 APD =0	S.L.=0 APD =0
Spot Repair Of Unpaved Shoulders	S.L.=3.0 APD =51.4	S.L.=4.7 APD =46.4	S.L.=6.2 APD =41.8
Blading Shoulders	S.L.=2.7 APD =10.2	S.L.=4.4 APD =10.6	S.L.=4.8 APD =11.3
Clipping Shoulders	S.L.=33.3 APD =1.5	S.L.=37.1 APD =1.9	S.L.=42.5 APD =2.3
Recondition Shoulders	S.L.=36.0 APD =3.3	S.L.=38.0 APD =3.4	S.L.=38.0 APD =3.4
Clean and Reshape Ditches	S.L.=28.6 APD =546	S.L.=30.8 APD =696	S.L.=34.4 APD =846
Motor Patrol Ditching	S.L.=28.9 APD =1.0	S.L.=29.8 APD =1.3	S.L.=30.5 APD =1.7

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

Table 6
Service Life and Daily Accomplishments
Shoulder/Ditch Condition; FAIR

ACTIVITY	Effective Service Life And Associated Accomplishments		
	MINIMUM	AVERAGE	MAXIMUM
Full Width Shoulder Seal	S.L.=24.0 APD =65.0	S.L.=30.6 APD =73.5	S.L.=37.2 APD =83.5
Spot Repair Of Unpaved Shoulders	S.L.=6.3 APD =32.7	S.L.=8.3 APD =30.5	S.L.=10.9 APD =27.7
Blading Shoulders	S.L.=5.7 APD =12.4	S.L.=7.2 APD =13.2	S.L.=7.8 APD =14.4
Clipping Shoulders	S.L.=39.3 APD =2.8	S.L.=43.1 APD =3.2	S.L.=47.5 APD =3.7
Recondition Shoulders	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5	S.L.=46.0 APD =4.5
Clean and Reshape Ditches	S.L.=42.7 APD =1082	S.L.=45.3 APD =1255	S.L.=48.0 APD =1436
Motor Patrol Ditching	S.L.=36.0 APD =1.7	S.L.=38.3 APD =2.0	S.L.=42.8 APD =2.5

S.L. = Service Life (Months)

APD = Accomplishments Per Day (Units in Table 1)

Interim Report

ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL USE OF ROUTINE MAINTENANCE FUNDS: AN ESTIMATION OF SERVICE LIFE AND COST OF ROUTINE MAINTENANCE ACTIVITIES

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Purdue University
West Lafayette, Indiana
August 27, 1986
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Interim Report

ASSESSMENT OF ROUTINE MAINTENANCE NEEDS AND OPTIMAL USE OF MAINTENANCE FUNDS: AN ESTIMATION OF SERVICE LIFE AND COST OF ROUTINE MAINTENANCE ACTIVITIES

TO: H. L. Michael, Director
Joint Highway Research Project

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

August 27, 1986
Revised April 3, 1987
Project No:C-36-63K

File: 9-7-11

Attached is the Interim Report on the HPR Part II Study entitled, "Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds: An Estimation of Service Life and Cost of Routine Maintenance Activities." This interim report covers the Tasks A, B and D dealing with the estimation of service life and cost of routine maintenance activities. The study was conducted by Kieran Feighan under the direction of Profs. Kumares C. Sinha and Thomas D. White.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

K. C. Sinha
Research Engineer

KCS/rrp

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16. Abstract

This report presents the findings of the research work that was undertaken to evaluate the service life and cost of routine maintenance activities. The estimates include various pavement, shoulder and drainage - related activities. The procedure was based on a statistical random survey of unit foremen using a questionnaire approach. These estimates will be used to identify cost-effective treatments at project and network level.

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CHAPTER 1

INTRODUCTION

Interest in Maintenance Management has grown steadily in the last ten years or so. This interest has been largely motivated by a desire to obtain a greater degree of control and standardization of approach in order to achieve ultimately a better return per dollar invested. Inevitably, most of the research to date has been done in the major maintenance area where the high cost reconstruction and rehabilitation work is carried out.

However, interest is now beginning to turn to the optimal allocation of routine maintenance resources. A primary factor in this movement is the realization that routine maintenance greatly affects the overall pavement performance. In order to develop a network level pavement management system, it is essential that the role of routine maintenance be explicitly considered. Furthermore, significant sums of monies are spent by the state on routine maintenance activities without matching federal funding, while the cost of new construction or major rehabilitation may be met by federal grants of up to 90% of the overall expenditure. Consequently, highway

personnel are now beginning to seek a means of obtaining better control of routine maintenance activities.

There are many factors which make the task of managing the routine maintenance system difficult. In general, there are diverse routine maintenance activities that are undertaken over extended areas. The cost of undertaking any given activity at a particular location is relatively low compared to major activities. Consequently, it is difficult to quantify or demonstrate to maintenance personnel the benefit of changing existing work practises, choice of treatment and so on when only a marginal improvement results. Of course, when all the marginal improvements are combined at the network or state level, the benefit would indeed be substantial. Unfortunately, no systematic data collection effort has been undertaken to quantify the differences between alternative maintenance treatments for any given pavement defect in terms of overall cost-effectiveness.

There are major differences of opinion among maintenance personnel in relation to the preferred method of dealing with any routine maintenance defect. Obviously then, the first step in establishing an effective routine maintenance management program is to attempt to locate and define the appropriate data base necessary for decision making. This can only be done through extensive consultation with personnel experienced in the field of

routine maintenance. No maintenance program could hope to function successfully unless founded upon a base of relevant expertise.

Another factor which makes effective routine maintenance management more difficult is the scale of the operation. In the field of major maintenance, the projects under consideration in a given year will amount to several hundred miles of pavement. For this reason, it is possible to collect very detailed information on past history, materials, traffic volumes and all other relevant data. The projection models of life and performance can be formulated with this degree of detail in mind.

However, in the routine maintenance area, the scope of the operation involves literally tens of thousands of miles which must be maintained every year. Dozens of activities are involved, most of which are highly labor-intensive. The roadways in question may vary from six-lane Interstate highways to lightly trafficked two-lane roadways. It is quite obvious that a different, more rudimentary methodology is neccessitated by the sheer logistics of the operation in question.

The main purpose of this research was to identify service life and costs of various routine maintenance activities so that the information could be used in the existing maintenance management program in Indiana. The

material in Chapter 2 deals with the existing maintenance set-up in Indiana; the managerial network, the levels of responsibility and the management procedures already in operation. In Chapter 3, the available literature on maintenance management in general is reviewed. Approaches relevant for application and modification to the specific field of routine maintenance in Indiana are identified. Published material on service life and cost of routine maintenance activities are also examined.

In Chapter 4, the data collection system proposed for use in Indiana is outlined. The fundamental reasoning which shows how the conflict in data requirements between a managerial system and a field operation system can be resolved is explained. Chapter 5 describes the survey methodology used in obtaining estimates of treatment service life and costs for Indiana. These estimates are required to determine the best alternative to use in treating the deficiencies identified in the unit foreman data collection effort. Chapter 6 contains an analysisof the results of the survey for all the routine maintenance activities within the scope of the present research.

The material in Chapter 7 is concerned with the general topic of priority selection. Specific application of priority setting to routine maintenance is outlined and the broadening of the current, basic priority setting in use in Indiana to a system workable within a detailed

routine maintenance management program is explained with particular reference to the part played by the service life and cost estimates obtained in Chapter 6. Finally, in Chapter 8, an overall set of conclusions and recommendations based on the research carried out is given.

CHAPTER 2

ROUTINE MAINTENANCE IN INDIANA

2.1 General Background

Routine maintenance involves recurring expenditure for the upkeep of a highway system. In Indiana there are sixty-three maintenance activities in eight broad categories: roadway and shoulder, roadside, drainage, bridge, traffic, winter and emergency, service, and other. The responsibility for routine maintenance of the state highway system in Indiana is carried by the Maintenance Division of the Indiana Department of Highways. This division oversees the upkeep of approximately 11,000 miles of paved roads. It is obvious that given a network of this magnitude, the expenditure on routine maintenance is inevitably a very large percentage of the total maintenance budget available.

In fact, the total expenditure on routine maintenance in 1985 was set at approximately 100 million dollars which represents almost 47 percent of the overall budget of the IDOH [2]. This figure becomes even more significant when it is realized that routine maintenance activities are funded almost entirely from state-generated funding, in contrast with major maintenance or new construction which draws heavily from federal funds. It is clear, therefore, that any system or concept that can improve administration or implementation of routine activities could have a major financial benefit to the state.

For the purposes of administration, the state of Indiana is divided into 7 districts. Each of these districts is then further sub-divided into subdistricts; there is a total of 37 subdistricts altogether in the state. The subdistrict is thus the basic cell as far as financial administration is concerned.

However, from a maintenance work viewpoint, the subdistrict is too large to function effectively as a work unit, so the subdistrict in turn is divided into 3 or 4 units. A typical unit is comprised of approximately 140 miles of paved roadway. The primary responsibility for maintenance work carried out within each unit is held by the unit foreman. This research is being carried out at unit foreman level as this is seen to be the foundation upon which the whole routine maintenance structure is built.

2.2 Description of Existing Procedures

The backbone of the system of operation in the IDOH Division of Maintenance is the Management Systems Procedures Manual (3). This is a comprehensive and detailed document that sets out:

1. The duties and responsibilities of maintenance managers at all levels of management within the organization.

2. A basis for establishing and updating maintenance standards.

3. Procedures for developing maintenance programs and performance budgets.

4. Procedures for authorizing and scheduling maintenance work.

5. Procedures for evaluating work performance.

The items of particular relevance to routine maintenance are the Field Operators Manual, Crew Day Cards, Maintenance Needed Reports and Annual Workload Planning Data (Quantity Standards).

The Field Operators Manual [24] basically consists of a set of performance standards for each designated maintenance activity. The performance standard gives a description of the activity and a recommended work method as well as the standard crew size, equipment complement and average daily production. Thus the manual provides a basis for development of work programs and budgets as well as for scheduling and performing work.

The Crew Day Cards provide a means of authorization of work to be done and a record of work completed. One is given to each crew leader every morning and it details the nature and location of the work to be performed as well as the employees and equipment assigned. At the end of the

day, the crew leader fills in the accomplishments for that day as well as the manhours worked, the material and equipment used and the location or locations where the work was done.

The Maintenance Needed Reports are simply cards carried by the unit foreman on which he notes down any deficiencies that need to be corrected as he inspects the roads within his unit. The Quantity Standards give an estimate of the amount of work anticipated per standard unit (e.g. per mile) on an annual basis for each activity. Thus the subdistrict personnel have at least a starting point to work from in estimating the quantities required.

2.3 Chapter Summary

It can be seen that there is an extensive effort involved in developing a workable maintenance management system in Indiana. It is recognized that the system is functioning satisfactorily at the network level. The approach and methodology advocated in this research have been developed with the explicit purpose of staying as close to the present procedures as possible. It is believed that a number of significant benefits can be gained with very little modification to the existing setup.

CHAPTER 3

LITERATURE REVIEW

There has been much interest and application of Pavement Management Systems within the last ten years or so. However, the existing Pavement Management Systems have generally left routine maintenance out of explicit consideration [16]. In fact a fundamental observation that can be made on research to date in the incorporation of routine maintenance into PMS is that there is little or no relevant data available. This current research is directed to identifying approaches within PMS relevant to the incorporation of routine maintenance data into a working model.

3.1 PMS Condition Sampling Methodology

Many differing approaches have been taken to the collection of data for use in Pavement Management Systems. These approaches were developed with differing goals in mind and hence there is no one standard model in the area of PMS. Most of the methods in use fall within one of three general categories; Statistical Sampling, Comprehensive Sampling and Windshield Survey approach.

3.1.1 Statistical Sampling

Many agencies [10,12,15] use a statistical sampling approach in their pavement condition data collection. This method involves identifying lengths of roadway typical of sections having a certain traffic volume or classification and obtaining representative samples of all such possible sections within the state. This approach is advantageous in that there is a reduced total volume of data to be collected and consequently the data can be accumulated more quickly with less manpower. The information gathered on the particular sections can be more detailed compared to a comprehensive condition survey and the manpower needs are reduced.

The main drawback to this approach is that such information can only be used at an aggregated level by the nature of the procedure. Actual comprehensive data on the condition of the state's highways is not obtained, only statistical inference as to what the likely condition is in general. While this inference may, in fact, give a true overall picture of the condition of the network, it cannot tell or predict where there is a particular level of distress. This type of collection effort is generally conducted on a more frequent basis than a comprehensive-type procedure, usually annually or bi-annually.

3.1.2 Comprehensive Sampling

An alternative data collection approach involves conducting a comprehensive type of pavement condition evaluation. The comprehensive approach requires evaluation of all sections of the state's highways. Notable systems based on this approach are operational in Washington, California and Texas. The particular methodology varies from system to system but the general approach is basically as follows. A given stretch of roadway is deemed to be made up of relatively homogeneous sections (homogeneous in terms of pavement type and distress). Each section is identified in terms of milepost readings or some other standard system. A representative section within the designated stretch is then evaluated using standard definitions and measurements of distress level severity and quantity.

The premise upon which this approach is based is that the accumulated information can be used both at project and at network level. The entire data base will give a picture of the statewide pavement condition and will aid in the optimization of fund-allocation. In addition, specific, locatable projects can be compared and tradeoffs made. The drawbacks of the system include the very large amount of data that must be collected and processed and the amount of resources utilized towards this end. Another major disadvantage is that in many cases there is a

relatively slow rate of change of deterioration of the pavement structure so that a large amount of data is accumulated for no real benefit in these cases.

In general, comprehensive data collection efforts tend to be based on obtaining a condition rating of each pavement section approximately every two years. In the California system [14], for example, the condition survey is conducted every two years using District personnel. The survey is completed in all districts within a six months time frame. The two year period is generally the time required to evaluate and analyze all sections within the state with the manpower, computer facilities etc., available.

Some other systems use a centralized survey staff from headquarters who do condition surveys on a continuous basis. This centralized approach has an advantage in that it should eliminate much of the variability in condition assessment and also reduce training effort. However it has the disadvantage that not all areas are surveyed at the same time of the year. Furthermore, Washington State, which operates on a continuous survey basis, has found that motivation of staff is a particular problem due mainly to the extensive travel involved [8].

3.1.3 Windshield Approach

The third major approach to data collection is the Windshield Survey Method [9] as used by the New York Department of Transportation (NYDOT). The statistical sampling procedure was not considered suitable because information on project selection and priority ordering would not be obtainable. However due to lack of available funds and staff, it was felt that a comprehensive pavement monitoring approach was also not feasible. In lieu of these approaches, NYDOT developed a windshield survey technique which requires the rater to stop and measure observed deficiencies above a certain threshold level only (i.e. data on non-distressed pavements is not collected at all). The basic concept is one of a filtering mechanism that intercepts potential problems only but nevertheless provides overall monitoring capability by examining the entire network condition.

In application of this method, there is rapid turnaround in data collection by NYDOT which is achieved by utilizing the department's regional offices to provide trained two-man teams to monitor the pavements.

3.2 Type and Use of Data Collected

The above three condition surveys use, to a greater or lesser degree, specific distress types (e.g. ravelling,

Alligator Cracking) in pavement examination and require the observer to quantify measurements of distress. Some agencies require the observers to measure actually the quantity of distress on a lineal foot or square yard basis while others require the observers to link the observed distress to a set of guidelines and/or photographs and to identify either directly or on a sliding scale the particular level of distress observed.

In no case has there been a mention of a pavement maintenance system which uses unit foremen as pavement condition data collectors on a systematic basis. This is primarily due to the level of quantitative and detailed information required by the respective systems. The NCHRP Synthesis on Collection and Use of Pavement Condition Data (6) has identified the following uses of the collected data:

1. To establish projects in need of maintenance or rehabilitation

2. To establish types of maintenance or rehabilitation currently required

3. To establish types and schedules of maintenance and rehabilitation to be undertaken in the future to minimize life-cycle costs or to maximize net benefit.

The synthesis further breaks down the whole concept of Pavement Management Systems into its three constituent parts, namely

1. Identification of priorities

2. Establishment of Maintenance and Rehabilitation Strategies i.e. an action plan on a year-to-year basis

3. Projection and prediction of pavement performance in the future

To accomplish the above tasks, the pavement condition data are obtained through one of the methods described earlier. These data are then transformed, usually into a numerical rating value, for each evaluated section based on the levels of distress noted by the observer. Further information on the rideability and roughness of the pavement is usually obtained by means of a Mays Meter or other automatic device. This information is combined with the condition data to arrive at an overall pavement "score" for each section.

3.3 Applications of PMS Concepts

It is quickly apparent that there is no system that can be directly related to the proposed improvement to theroutine maintenance management system for use in Indiana. Under

this proposed improvement, unit foremen will carry out a complete inspection of their road network every six months and will indicate the pavement, shoulder and drainage condition on forms provided. The statistical sampling technique is the only technique which could meet the semi-annual time criterion, but as the information gathered can be utilized only at network level, it is of very limited use to routine maintenance personnel. The comprehensive sampling technique offers project level feasibility but would require too much time and input from the foremen to be workable. The NYDOT study offers a middle approach which reduces the workload but again it requires very detailed measurement of distress types. A resolution of the problem is outlined in the following chapter.

3.4 Approaches in Routine Maintenance

Little attention has been given to the issue of routine maintenance as an entity within itself. Management of routine maintenance activities is a difficult task, recognised by those involved in the field. A county engineer in Iowa (5) raises the following pertinent questions. Are we planning our maintenance as we should ? Are we keeping records of what we are doing for an efficient maintenance operation ? He concludes that the sophistication and scope of PMS and MMS are probably not

applicable at routine maintenance level but states that the need for a manageable system is definitely there.

3.4.1 Recordable Condition Approach

One approach relevant to routine maintenance is a recordable condition report for measuring the quality of highway maintenance (4). This approach is based on a windshield survey method and involves distress types and measurement quantities directly useable from this standpoint. The method was originally conceived purely to compare the quality of maintenance from year to year within a district or between districts in the same year. However, the concept has potential application for the proposed routine maintenance system.

3.4.2 Ontario Approach

Ontario (13) has established a routine maintenance system whose operation is independent of the major maintenance system in existence there. The Pavement Maintenance Guidelines Approach deals solely with routine maintenance from the operator or motor-patrol standpoint. It is basically a systematic strategy of pavement maintenance designed to obtain consistent treatment of similiar distress manifestations throughout the state.

The guidelines consist of a series of photographs and descriptions of most of the common pavement deficiencies.

Recommended treatments for each level of distress are included as are the expected service lives of all the alternative maintenance treatments. These estimates were based on detailed consultation with individuals with many years of field experience.

The approach taken is to address the following questions to the field personnel faced with a particular problem. (1) What is the problem ? (2) How bad is the problem ? (3) How big is the problem ? When the operator answers these questions by locating the relevant description and photographs in the guidelines he can then directly read off the recommended treatment. The operator is also urged to select the most cost-effective treatment when he has a number of optional treatments by calculating an equivalent annual cost using the Unit Cost of treatment and expected life of the treatment.

This approach with the procedure based at operator or unit-foreman level would seem to be the most viable option. Of course the Ontario system is not suitable for adoption in its entirity as it is not, and does not pretend to be, a routine maintenance management system. It does not obtain data gathered in a systematic way at specified times that could be used at network level. What needs to be done is to incorporate the philosophy and methodology of the Guidelines with the items of interest which we have selected from the Pavement Management

Systems approach and amalgamate the two to produce a workable and useful system for routine maintenance management in Indiana.

3.5 Service Life of Routine Maintenance Treatments

There is a very large amount of published material related to the application of routine maintenance treatments. However, the vast majority of this material relates to the techniques for performing such treatments and there is very little specific information on the actual expected service life of these treatments. The techniques to be used by maintenance crews in Indiana in applying the treatments are already specified in the Field Operations Handbook [24]. Consequently, the main item of interest in reviewing the available literature is to identify service life estimates where the treatment approach and techniqnes are comparable to Indiana practises.

The single source most useful in this regard was found to be the Ontario publication, "Pavement Maintenace Guidelines; Distresses, Maintenance Alternatives, Performance Standards", [13]. This manual gives estimates of service life for differing levels of defect severity, generally defined as slight, moderate and severe, and also includes detailed descriptions of the procedures to be followed in performing each activity.

Service life estimates are given for Ontario [13] and other relevant estimates in Table 1. The other estimates have been obtained from various sources where the accompanying descriptions of treatment procedure indicated a methodology reasonably close to the Indiana approach.

3.5.1 Shallow Patching

Within the area of shallow patching, materials were generally defined to be hot mix or cold mix patches. The NCHRP Synthesis #64, Bituminous Patching Mixtures [29], offers a good general background to the subject of patching. Patching materials can fail by rutting or shoving, by binder stripping or by ravelling. The type and quality of the binder can play an important role in determining the ultimate service life obtained. In hot mix mixtures, the binder binds the aggregate together to provide good stability and durability. However, as the mix is being laid hot, the binder need only have fluid properties at elevated temperatures.

On the other hand, the binder must retain a degree of workability at almost all temperatures for cold-laid materials. The binder must therefore be fluid enough to be handled easily over a wide temperature range yet must increase consistency rapidly when compacted in the field. Generally, the hot mix type patch will be longer lasting as it can achieve greater stability because of less

Table 1
Average Service Life Estimates

AVERAGE SERVICE LIFE ESTIMATES (MONTHS)		
Activity	Ontario [13]	Other
Shallow Patching (201)		
Hot Mix	36-48	-
Cold Mix	6-12	1-24 [28]
Premix Levelling (203)		
Hot Mix	36-48	-
Seal Coat (205)		
Chip Seal	30-36	12-60 [27]
Sand Seal	24-36	-
Sealing Long. Cracks and Joints (206)	36	40 [5] 40-60 [18] 36-72 [17]
Crack Sealing (207)	12 12-24 [28]	12-24 [17]
Pipe Replacement	-	300-480 [19]

concern about workability at low temperatures. Hot mix patches generally are placed only during the period from April to October when the batch plants are in operation. The more favorable climatic and sub-surface conditions during this period also aid in producing greater longevity.

Another author, J.R. Steel [30] has defined patch failure as occurring in the following ways.

1. Deterioration at edges with no failure in surface.

2. Material picking out of patch surface.

3. Deformation of patch surface relative to road surface.

4. Haunch failure.

This paper also pointed out that proper training of maintenance personnel in the correct method of placing patches will result in longer service lifes. Again, this is a factor that must be taken into account in comparing service life estimates.

The Pennsylvania DOT have carried out extensive investigations of cold mix patches and have identified a number of tradeoffs that affect both the service life and the ease of placement [31].

Among the most important factors were:

1. Aggregate gradation; Open graded mixtures have better workability while dense graded mixtures improve durability.

2. Aggregate shape; Rounded aggregate shape improves workability while angular aggregates produce greater mix stability.

3. Binder viscosity; low binder viscosity produces greater mix storeability properties while higher viscosity binder provides better in-situ cohesion.

4. Binder content; relatively high binder content is necessary for durability, but for storage purposes, the binder content should be on the low side as excesa binder will drain from the mix when it is placed hot into the stockpile.

For all of the aforementioned reasons, therefore, it is very difficult to compare service life obtained in different geographical and jurisdictional areas, and the estimates cannot be regarded as anything other than generalized indicators.

3.5.2 Premix Levelling

The premix levelling values obtained are explicable on the same basis used for the hot and cold mix patches. Again,

the service life obtained depends greatly on the quality of material used, the techniques of placing the material used, the roadway condition and the local climate. Therefore the values obtained in other areas, while being useful as general indicators, cannot be taken directly and used in Indiana. Furhermore, the range of these estimates are extremely wide and too gross for use within a maintenance management system. Consequently, it was necessary to perform a seperate survey for premix levelling and all other activities to obtain useful, relevant and detailed data on service life in Indiana.

3.5.3 Seal Coat

The estimates of seal coat service life in Table 1 are obtained from Ontario [13] and from Darter and Shahin [27]. The service life will vary with existing roadway, climatic and traffic characteristics. Darter and Shahin estimate a seal coat should last from 1 to 3 years while an opengraded seal coat should last for up to 5 years.

3.5.4 Sealing Cracks and Joints

A problem arises in establishing comparative values for Sealing Longitudinal Cracks and Joints and for Sealing Cracks. The problem is basically one of nomenclature. The activity described as "sealing" in Indiana should more correctly be described as "filling". The procedure followed is simply to clean out the cracks or joints with

compressed air and then apply a liquid bituminous sealant using a squeegee. Typically, sealants are divided into three main groups; these are hot-poured sealants, cold-poured sealants and preformed sealants [32]. Usually the sealants are composed of rubberized asphalt or polymeric compounds designed to have adequate adhesion and cohesion and to resist extrusion. Preformed sealants are generally composed of styrene, urethane, neoprene or other synthetic rubbers.

Considerable care is advised in ensuring that an acceptable reservoir shape factor is provided for satisfactory performance of the sealant. A number of different sources [4,17,18,32] have estimated average service life for these sealants to be in the range of three to seven years. However, two references were located [13,27] that describe crack filling activities comparable to the current Indiana procedure and these estimates were both in the one to two year range. The term crack sealing is retained in this thesis in referring to the Indiana procedure to be consistent with the Management Systems Procedures Manual [3].

3.5.5 Pipe Replacement

The NCHRP Synthesis, Durability of Drainage Pipe, outlines several methods of defining pipe failure [19]. These are on the basis of (i) Field Performance surveys, (ii) field

prototype tests, (iii) laboratory test methods and (iv) analytical methods. The synthesis recommends that designers should look for pipe service life estimates of greater than 25 years in secondary facilities and greater than 40 years in major facilities. These figures were arrived at based on a survey of most of the state highway agencies in the United States. The service life values obtained in Indiana will be discussed in detail in Chapter 6, but are certainly comparable in magnitude with the synthesis estimates. It was not possible to locate relevant service life estimates in the literature review for the unpaved shoulder activities or for reshaping or motor-patrolling of drainage ditches.

3.6 Routine Maintenance Cost Data

There is a reasonable amount of published data on the cost of some routine maintenance activities. Unfortunately, there are two factors which lessen the usefulness of the data for the proposed improvement to the Indiana RMMS. Firstly, the standard unit of each activity that is costed varies from state to state. For example, sealing cracks can be priced in terms of gallons, square yards, tons, linear feet or lane-miles. It is extremely difficult to convert accurately between thes various units.

Secondly, even when different states use the same unit of costing, the costs per unit can be vastly

different. The reasons for the difference include different materials, different methods of placement of the materials and differng workcrews among others. Allied to these complicating factors is the problem that unit costs are available for only a limited number of routine maintenance activitiés. Consequently, the need exists to perform a study to determine unit costs specifically for Indiana. This was carried out as part of the present research and is detailed in later chapters.

The activities identified that did have unit costs useable for comparison purposes were sealing cracks and chip seal. The cost per gallon of sealing cracks was \$8.43 in California, \$6.14 in Nevada, \$6.36 in New Jersey and \$2.34 in North Dakota [33]. It is readily apparent that there is a wide variety in the prices quoted. The spread of values is also very large for chip seal activities. The unit cost estimates obtained per square yard include \$0.58 in California, \$0.45 in Florida, \$0.23 in Louisiana, \$0.31 in Nevada and \$0.44 in North Dakota [33]. It is obvious that unit costs must be obtained for the specific case of Indiana maintenance activities.

CHAPTER 4

OUTLINE AND RATIONALE OF PROPOSED SYSTEM

There is an ever-increasing realization of the importance of routine maintenance both as a form of maintaining pavement and roadside serviceability above certain, prescribed, minimum standards and as a major consumer of limited state highway funds. The proposed procedure for assessing service life and cost of maintenance activities is intended to be useful as an aid to management in programming the available funds to obtain better control and improved maintenance results.

4.1 Adoption of Implementable Systems

A maintenance management system, to function effectively, must meet several criteria. These criteria have been encapsulated most succintly as follows [11]

1. System should use currently available user agency data.

2. System should be structured to minimize the difficulty of implementation by user agency.

3. System should make maximum use of the experience and judgment of agency experts.

4. System should be structured to permit future modifications and improvements to be made.

In the development of a RMMS for Indiana, new procedures and additional workload need to be minimized. The philosophy is that the data collection and subsequent implementation should be a "bottom-up" type of operation which will enhance the chances of success.

The implementation of any management program ultimately depends on (1) the accuracy and exhaustiveness of its data base and (2) the willingness and cooperation of the people in the field who must carry it out. In the proposed procedure advocated for Indiana, the unit foreman will function as both data collector and implementor and therefore the foreman's agreement and positive input into the formulation of the program is essential.

4.2 Limitations of PMS Application

The goal of current pavement and major maintenance management programs is primarily application at network level. The approach involves sampling the highway system at different points and deducing its present and future overall condition from a wide variety of methods. On the basis of this information, decisions can be made as to the

best use of overall funds to maximize the benefits gained to the system from the expenditure of these funds on a longterm basis. Such an approach is not feasible within the routine maintenance environment .

In practise, routine maintenance is basically a reactive- type system operating on a short-term basis. In the field of pavements in Indiana it encompasses, in the main, shallow and full-depth patching, sealing cracks and joints, pre-mix levelling and seal coating. What routine maintenance teams set out to do is to try to keep the pavement and roadside in a serviceable condition by correcting the deficiencies that are there now. Its function is not to assess the likelihood of a pavement cracking or failing in two, five or ten years time. Hence, data collected for routine maintenance purposes do not need to fit into a predictive model to the same extent that major maintenance condition data do, and consequently can be less detailed in measurement terms.

If any overall management system is to succeed, it must obtain information which is relevant and upon the basis of which realistic and implementable decisions can be made. The crux of the issue is to come up with a scheme which the unit foremen and subdistrict supervisors feel is of direct use to them and which they will feel comfortable with but which, at the same time, offers data useful for utilization at a higher level in the management structure.

The current operating practises in routine maintenance activities in Indiana are based on an "as-noticed" basis at unit foreman level. As the foreman drives the roads within his unit, he notes down any deficiences or faults that need to be corrected. These deficiencies are then scheduled by the general foreman for correction. This approach has functioned reasonably well within Indiana but a large variation in treatment and service life still exists. Furthermore, this information is not utilized at network level so that realistic planning on a district-wide or statewide basis is hampered by a lack of relevant data. The objective of the present research effort is to improve the routine maintenance management program so that such information will be obtained on a systematic basis.

4.3 Outline of Proposed System

The basis of data collection for the proposed new RMMS procedure will be a complete bi-annual inspection carried out by the unit foremen of their respective areas. This inspection will consist of the foremen filling out standard forms evaluating the condition of every roadway and surrounding area within their respective units. The information gathered will form the raw database for the RMMS. Information on the cost and service life of the relevant routine maintenance activities will be

incorporated within the management program. On the basis of these parameters and the condition data input, a maintenance program that optimizes the benefits accrued for a given expenditure can be obtained. This is the basic outline for the proposed RMMS.

4.3.1 Scope of Proposed Procedure

Activities included in the proposed systematic data collection procedure will encompass the following three categories; (a) Pavements, (b) Shoulders and (c) Drainage. Quantifying data needs for the diverse activities inherently difficult to quantify must be balanced with the needs to minimize both time spent and change to the existing system.

As the intention of the procedure is that all roads within the state will be assesssed on a six-monthly basis, the very nature of the system also precludes the possibility of detailed measurement of deficiencies. Also by the nature of the system, certain items which normally fall within the general heading of routine maintenance must be left out of the management program. These include such activities or distress manifestations as snow and ice removal, sign replacement and guardrail replacement due to knockdown, blowups and relief of flooding. It is simply not feasible to require a foreman to look at a stretch of road in October and estimate the likely amount of snow to

be removed within the following six months.

4.3.2 Contrast with Existing Approach

The basic difference between the proposed system and the existing system is essentially the process of data collection which will now be put on a systematic, state-wide basis. Through consultation with the foremen, their supervisors and engineering maintenance staff, standard levels of deficiency and distress which warrant inclusion in the category of remedial action within the following six months can be identified. The elegance of this scheme is that it simplifies the data to be collected and produces a common basis for deciding upon treatment of deficiency under various categories.

Another intrinsic and vitally important consequence is that the forms to be filled out by the foremen can be simplified to a condition much more suitable and acceptable at foreman level rather than the formidable and often unwieldy forms which would have to be considered to support a modified major maintenance approach. Of course, simplification per se is not particularly a noteworthy achievement unless sound and relevant information usable at a management level can be deduced from the forms. To this end, a major attempt to calibrate foremen's readings and assessment of needed remedial levels of distress to actual, physical field measurements is being made [25].

In actual implementation, photographs may be used for training purposes and as a guide to the foremen in their decision-making process as well as to produce greater standardization of approach. It is also recognised that the foremen are basically the experienced, on-the-spot decisionmakers and use their discretion and knowledge in considering situations not directly governed by the guidelines. In this way, it should be possible to accumulate, via the forms, extensive information on the amount of each activity which needs to be carried out to remedy conditions within six months.

4.4 Uses of Proposed Data

The information gathered can be correlated by activity, county, sub-district and district level. It will form the essential information base upon which decisions to optimize routine maintenance funding can be made. It is at this stage that senior management can decide the priorities in the allocation of funds by activity and by district. Management is also afforded the opportunity to shape future maintenance practises by designating funds for some activities over others, for example encouraging sealing rather than patching. Another very important consequence is that senior staff will have available a definite means to demonstrate to legislators and administrators the shortfall between needs and available

funds even on a six-month basis. This can be directly translated into examples of maintenance shortfalls and consequences which will result if budgets are frozen or cut. Also, trends demonstrating the effectiveness of routine maintenance activities over the longterm period can be identified with the help of 'this database.

Once management decisions on fund allocation have been made, the gathered data can be used at district level to allocate funds on a more localized and needs-based system. For example, at network level it may be decided that 15% of available funds be spent on patching. This does not mean that every county or sub-district must spend exactly 15% of their budget on patching as funds can be distributed within each activity according to the amount of patching required (as indicated on the forms). Thus middle management will still be able to exert considerable influence in the eventual expenditure of specific dollars.

Similiarly, personnel at subdistrict and unit level will know where the worst distress manifestations of any particular type will be and they will be able to react accordingly. Hence a better return for dollar investment in maintenance should be obtained in addition to valuable system- and district-level data on the present condition of the roads and highway environment throughout the state of Indiana.

In referring back to the original criteria of Section 4.1 for the adoption of an implementable Management System, it can be seen that the proposed procedure is fully in line with those recommendations. Currently available IDOH personnel and data will be used as much as possible in determining costs, service-life, overall expenditure and other information. Secondly, the proposed data collection system is specifically structured and aimed so that it stays as close to the existing procedures as possible while providing the necessary data for management decision-making. Thirdly, as has been outlined, the system is based on the expertise and knowledge of the existing IDOH personnel at the field level.

The fourth criterion which the system should meet is that it should be modular to permit future modifications annd improvements to be made. There is no doubt that the system will require fine-tuning in order to operate effectively and efficiently. Several measurements which initially may not have been deemed to be important may subsequently be included or vice versa. It is not possible at this stage to predict the problems and misunderstandings which may arise. Also, of course, as the database grows at six-month intervals it will be possible to foresee and predict trends and variations which can only be hypothesized at the present time.

However, the structure of the system is such that it can easily and quickly be modified in small or large measure with very little difficulty. It is believed that the proposed procedure can be made viable in a short period of time and will provide an efficient, effective and workable tool in the hands of all routine maintenance personnel at all levels of management.

4.5 Interaction Between Proposed RMMS and Indiana's PMS

A very pertinent and relevant question relates to how this proposed Routine Maintenance Management System is to fit into the overall context of a currently developing Pavement Management System. A pavement management system would ideally incorporate and co-ordinate all aspects of highway activities including both routine and major maintenance of pavements and shoulders.

The intent behind developing this proposed routine maintenance data collection procedure is first and foremost to aid in developing a system that can stand and function on its own. The Pavement Management System will not provide sufficient, relevant information to the routine maintenance personnel all down the line as the predictive and longterm nature of the data required for a PMS is not essentially compatible with the short-term nature of routine maintenance. For this reason, the proposed routine system will be tailored to respond to the

specific needs and resources of the routine maintenance section.

It must be stressed, however, that thought has also gone into the planning of the system so that the data collected can be of real use in the context of an overall management system. Firstly, data were collected to establish initial service life values and costs of a large number of routine maintenance activities. These estimates can be modified and updated as the database grows. These estimates can be location-specific, taking into account climatic conditions and other factors. Thus, accurate service life and cost estimates for routine maintenance activities throughout Indiana can be provided to the PMS in its consideration of routine maintenance as a treatment option.

Furthermore, actual condition data on pavement condition obtained through the RMMS can be compared with the condition predicted by the PMS program and modifications to the PMS can be performed, if neccessary. In this way, the RMMS could be a useful tool in checking or improving the prediction models used by the overall management system. Naturally, the converse should apply. If a section of roadway has been scheduled for major maintenance, such as reconstruction or resurfacing, in the following two years then the section number can be checked against the routine maintenance distress reports. An

advisory notice can then be sent to the local supervisor informing him of the proposed major rehabilitation so that an appropriate level of routine maintenance can be established. In this way, the unfortunate but frequent occurrences of large amounts of maintenance resources being wasted by carrying out extensive repair only to have the entire section resurfaced shortly thereafter can be reduced or, hopefully, eliminated.

It is envisioned that there will be comprehensive pavement condition surveys as part of the overall pavement management system but this inspection will operate in tandem with the routine maintenance program and will not be eliminated or negated by it. Both types of survey perform much the same operation with regard to pavements but function at different levels of complexity as the data collected are needed for two entirely different procedures and functions and cannot be amalgamated into one. Furthermore, the RMMS data collection effort is concerned with more than just pavement condition. It also involves shoulder and drainage activities and this scope could be expanded as the sytem evolves.

Certainly from the routine maintenance program viewpoint, every effort will be made to ensure that as much of the data collected as possible is useable by any overall system. It is realized that routine maintenance is a subset of the overall system and must be seen in that

light. However, it must be stressed again that the primary aim of this study is to produce a systematic data collection and analysis procedure that will be applied and utilized by routine maintenance personnel and consequently its main priority is to produce better return from routine maintenance funds and resources.

CHAPTER 5

TREATMENTS- SERVICE LIFE AND COST

There is a variety of treatment alternatives available for different types and levels of pavement and shoulder distress within the field of routine maintenance. All of these treatments will be effective to one degree or another, but a need exists to evaluate which methods produce the best solution to a given deficiency.

5.1 Uses of Data

The following uses have been put forward as justification for research into the estimation of expected service life and costs.

1. To estimate and allocate funds available.
2. To identify the most cost-effective solutions.
3. To monitor if change in work practises or materials significantly affect service life and to evaluate whether or not such changes are cost-effective.
4. To identify locations which consistently underscore the expected life of a given treatment to a

significant extent. In such cases, alternative treatments may be necessary.

5. To justify a change in emphasis at network level, e.g. advocating sealing (preventive maintenance) over patching (corrective maintenance).

6. To anticipate when necessary expenditure will re-occur.

7. To co-ordinate with PMS and other management systems in identifying the most cost-effective "holding" action until major rehabilitation or reconstruction can take place.

The need for such estimates within the currently advocated three-pronged approach to routine maintenance management in Indiana of (1) Consistency, (2) Priority and (3) Quality can also be readily seen.

It is desired that the operation of the routine maintenance program will lead to a situation whereby maintenance personnel throughout the state will be more consistent in their identification of, and proposed solution to, any given pavement problem. The consistency of problem identification will be addressed by use of standardized forms. Correction of the defects can only be made more consistent through adoption of the most cost-effective treatments in every case. However, to determine

initially what the preferred treatments will be, costs and expected service lives must be obtained.

In the establishment of priorities, economics must again be an important input factor. Certainly it will not be the only parameter to be considered; safety, environmental concerns, equipment and manpower available to name but a few will also need to be taken into account. Nevertheless, service life and related costs will be a vital aid in the decision-making process.

Thirdly, the issue of quality control must be confronted. Obviously, it is useless to make theoretical estimates and obtain the most cost-effective solution theoretically if that treatment does not perform as well as predicted in the field because of poor quality control. In the proposed RMMS, the greatest control over quality can be exerted by the unit and general foremen as they are the personnel in closest contact with the maintenance crew.

The service life values obtained in this research are based on the opinions of unit and general foremen throughout the state. Consequently, these estimates will serve as useful standards that the foremen can compare with the service lives being obtained by their own crews and advise them when substandard work is being performed.

An easy means of monitoring the degree to which this quality control is succeeding is to compare the effective service life obtained in the field to that expected of a treatment in which good standards of materials and workmanship are utilized. Furthermore, the performance of new or untried materials or methods can be evaluated and compared with existing materials by monitoring the effective service life obtained in the field.

5.2 Influences on Service Life Estimates

The expected service life of any maintenance treatment depends on a number of factors. The service life may vary depending on the degree of a particular distress or from distress type to distress type. There will also be unique influences particular to each general category of pavements, shoulders and drainage.

5.2.1 Pavements

The influencing factors on maintenance service life that have thus far been identified include:

1. Materials; The quality of the materials used should meet all relevant specifications and also should not have been adversely affected by improper storage or handling.

2. Workmanship; The quality of workmanship will have a great effect on the service life obtained. This category includes correct preparation of the pavement to be treated and proper handling and application techniques.

3. Traffic Volume and Composition; Higher overall volumes of traffic and higher percentages of heavy trucks will shorten the effective life of the treatment.

4. Sub-pavement Conditions; In some cases, the symptoms of the pavement defect are being treated but not the root cause. In these cases, the effective service life of the treatment will be shortened.

5. Climate; Large numbers of freeze-thaw cycles, high temperature gradients between day and night, high rainfall, large volumes of snow and ice and other climatic factors can all influence the effectiveness of the treatment.

6. Existing Pavement Type and Pavement Condition; The particular pavement type and condition will have a great effect on the longevity of treatment life. Naturally, a prticular treatment will have a shorter service life when the pavement condition is poor.

5.2.2 Shoulders

The main factors influencing shoulder maintenance effectiveness include;

1. Materials; As outlined in pavements above.

2. Workmanship; As outlined in pavements above.

3. Shoulder Encroachment and Roadway Geometry; On a narrow roadway carrying a high volume of commercial and heavy vehicles, a relatively high shoulder encroachment rate would be expected. The rate of encroachment also increases at curves. These factors will obviously have consequences for the effective life of such activities as spot repair and blading of unpaved shoulders. The degree to which traffic encroaches will also affect the amount and rate of development of build-up or drop-off in unpaved shoulders.

4. Sub-pavement Conditions; As discussed in pavements above.

5. Climate; As discussed in pavements above.

6. Existing Shoulder Condition.

5.2.3 Drainage Structures

There are many varied factors influencing the time required to render drainage ditches and pipes incapable of carrying the required runoff. A brief list of the most important is given below.

1. Climate.
2. Local Geology.
3. Soil Conditions.
4. Surface Area.
5. Vegetation Growth Rate.
6. Drainage Gradient (longitudinal).
7. Gradient of Drainage Ditches.
8. Size and Type of Drainage Pipes and Culverts.

It is apparent from the above discussion that any figures obtained in the survey of maintenance personnel carried out must be, of necessity, approximate figures. As the maintenance program goes into operation and progressively builds a database, a means will become available whereby the values initially used can be corrected or adjusted for use with designated categories of roadway sections.

5.3 Service Life and Associated Costs Study

A survey was carried out to determine effective service life and associated costs for routine maintenance activities in the areas of pavement, shoulder and drainage in Indiana. The survey involved completion of a series of forms by subdistrict maintenance personnel. The survey responses were statistically analyzed to provide necessary input parameters for the proposed RMMS.

5.3.1 Aims Of Study

The intention behind the compilation of the forms for the study was to obtain useful information on effective service life and costs of various routine maintenance activities. It is timely, therefore, to attempt to establish what can reasonably be expected to result from such a survey and consequently how best to tailor the survey to maximize the applicability and usefulness of the information obtained through the survey procedure.

What is being obtained in essence is an amalgamation of the opinions of routine maintenance personnel as to the longevity of treatment alternatives in Indiana. This may appear to be undesirable or not very useful at first sight given the inherent subjectivity involved. However, the intended purpose of obtaining these estimates was to establish a starting point in the analysis of priorities

and recommended methods of treatment. These estimates can be subsequently modified as the routine maintenance program progresses and builds a data base.

5.3.2 Actual versus Effective Service Life

A distinction between actual and effective service life must be made as it is crucial to the understanding of the uses to which the data accumulated can be put. An actual service life of a given treatment is the time elapsed from when the treatment is applied to the time when its condition falls below a prescribed, measurable value. This is not obtained in the present research. What is obtained is an estimate of the effective service life of a given treatment.

The effective service life can be defined as the time elapsed from when the treatment is applied until the time when, in the opinion of the foreman, it needs to be replaced.

In the establishment of a maintenance management program, what is of ultimate concern is the amount of money spent on any given activity and the way that available monies can be spent to produce the maximum good. In the area of routine maintenance, the operation and implementation of available funds is basically carried out by the field operatives. The unit foremen are the people

who decide in the first instance when and where work needs to be carried out. Hence, it is certainly very relevant and is finally perhaps more useful to obtain an estimate of how long a treatment lasts in the opinion of the foreman rather than in actuality.

For example, exhaustive and scientifically exact tests may determine that a given pothole repair could be left in place for three years and still be technically serviceable. However, if the foreman in evaluating his road system believes that the pothole repair is no longer satisfactory, for whatever reason, after two years, then it will be replaced after two years. To the management system that is ultimately concerned with when and how much money is spent, a service life estimate of two years is more relevant and more useful than the actual service life of three years, at least in the short-term.

Another important point that must be made is that the effective service lives are not necessarily obtainable from consideration of past records alone. The time elapsed between treatment and re-treatment can be either less than or greater than the effective service life. In some cases, a number of deficiencies displaying different levels of distress may be corrected at the same time due to geographic or equipment constraints. This practise would give an erroneously short service life estimate.

Conversely, due to equipment or economic constraints, a particular area may not be repaired for a considerable time after the unit foreman would deem it necessary to be repaired. Obviously an overestimate of effective service life would result in this situation. Consequently, it is desirable to attempt to obtain an idea of what the maintenance personnel perceive to be the treatment life.

It should be made clear that this is not a new or unique idea. Ontario (13) has already carried out such a survey as part of its Routine Maintenance Program and has incorporated the results , both service life estimates and costs, into its overall management system. It is believed that this approach will be of the most practical use to the Indiana Department of Highways, both as an item of interest unto itself and as a necessary step in establishing a Routine Maintenance Management Program.

5.3.3 Structure of Questionnaire

The questionnaire is laid out in a tabular/matrix type format, as shown in Appendix A. There are three categories of condition defined for each activity. These generally conform to the overall descriptors of poor, fair and good although there is obviously some variation in definition depending on the particular activity in question.

The other group of categories that sub-divides the condition input into cells consists of four components.

These correspond to minimum, average, maximum and attainable average. The first three components all refer to service life estimates currently given by the foremen with the existing manpower, equipment, materials and other constraints. It was decided to look for minimum and maximum values as well as an average value because it was felt that the average value alone could be misleading in terms of the overall range of performance.

The minimum value obtained is not intended to be the single worst case in the experience of the foreman in question but rather an indication of what is considered to be a realistic, poor service life value. Similarly, the maximum value should reflect a generally high service life value as opposed to the longest service life history known to the foreman.

The attainable average value is really a parameter intended for comparison purposes. It is an estimate by the foreman of the average effective service life when all necessary equipment, manpower and time are available to carry out the treatment work satisfactorily and appropriate work practises are followed. It was anticipated that in most cases this parameter should have the same value as the average life. The reason for this is that in general the maintenance personnel have indicated that availability of resources is not a major problem for a specific case.

The intention behind the attainable average value was to pinpoint where and why discrepancies do occur and subsequently to analyze the overall impact of these discrepancies in terms of cost-effectiveness.

Obviously, the procurement of these service life values is of limited use unless an explanation can be given of the differences which occur. A deliberate effort was made to obtain justification for the service life values given in all cases. In addition, estimates were also obtained of the average daily manhours and number of standard accomplishment units attained per day for each cell in the matrix for all activities. These figures were necessary to estimate cost information as will be explained later in this chapter.

In a survey such as this, a decision must be made as to the detail and accuracy of results which can be reasonably expected. A necessary tradeoff must be made between amount of data accquired and the consequent error induced in the respondent's estimates through boredom, desire to complete the survey rapidly and other reasons. It is believed that the survey structure struck a reasonable compromise in this regard.

5.3.4 Activities Considered in the Survey

The activities that are considered in this study are;

1. Shallow Patching (201)
2. Sealing Longitudinal Cracks and Joints (206)
3. Sealing Cracks (207)
4. Premix Levelling (203)
5. Seal Coating (205)
6. Full Width Shoulder Seal (204)
7. Spot Repair of Unpaved Shoulders (210)
8. Blading Shoulders (211)
9. Clipping Unpaved Shoulders (212)
10. Reconditioning Unpaved Shoulders (213)
11. Clean and Reshape Ditches (231)
12. Pipe Replacement (233)
13. Motor Patrol Ditching (234)

The numbers after each activity refer to the IDOH designated numbers which are used for computer coding purposes. A further breakdown is also necessary within the maintenance activities of shallow patching and seal coating. These sub-categories are as follows.

Shallow Patching;

1. Hot Mix Patch

2. Cold Mix Patch

3. Winter Mix Patch (A cold mix patch with fibres added to produce greater stability).

4. Cold or Winter Mix Patch placed after material is run through a Portapatcher.

Seal Coating;

1. Chip and Seal

2. Sand Seal

In discussion with experienced maintenance personnel in Indiana it became clear that there is generally not a great deal of overlap between the various activities in the treatment of a given deficiency. In other words, for any distress condition there is almost always one clearly desirable treatment for that condition. This contrasts with the number of alternatives present in major maintenance decision-making and simplifies the overall procedure considerably.

The few situations identified where alternative treatments are possible include;

1. Extensive Cracking; Seal Coat (Sand Seal or Chip and Seal versus Shallow Patching).

2. Ravelling/ Spalling; Joint Sealing versus Shallow Patching

3. Severe Shoulder Distress; Full Width Shoulder Seal versus Shallow Patching.

Apart from the above cases, it would seem that maintenance personnel have a clear preference in the treatment of any distress level of all common pavement defects.

5.3.5 Design Of Survey Procedure

To establish values for the service life and cost estimates, it was necessary to interview experienced personnel within the state. As previously explained, the state is divided into six administrative districts, each of which is comprised of a number of subdistricts. To interview personnel in all 37 of the subdistricts would have been extremely costly and time-consuming.

It was decided to choose subdistricts to take part in the survey by a process of stratified random sampling. Two subdistricts were selected at random from each district. The major advantages of stratified sampling

have been identified [26] as (1) efficiency, (2) information about subpopulations and (3) feasibility. The stratified sample is more efficient when the individual strata contain relatively homogenous elements as the variability for a given stratified random sample will be less than in a simple random sample of the same size.

It was considered reaonable to regard the elements as being relatively homogenous for each stratum in that each subdistrict within a district is subject to much the same climatic and topographic conditions and usually has the same source of maintenance materials and equipment. In addition to this, meetings of all subdistrict supervisors and general foremen within each district occur on a regular basis and consequently repair strategies and methods would be expected to be fairly consistent.

It was anticipated that due to the large difference in climate and topography between Northern and Southern Indiana there would be discernible patterns in the service life estimates for a number of the activities. The use of stratified sampling made it possible to examine and identify such trends as well as giving estimates of the overall population characteristics. From the point of view of feasibility, the fact that two subdistricts from each district were chosen meant that it was generally possible to interview in two subdistricts each day, thus reducing time and travel costs. The entire survey was

carried out in a two-week period at the end of June, 1985.

The subdistricts visited were at Columbus, Bloomington, Branchville, Petersburg, Ridgeville, Anderson, Fort Wayne, Bluffton, Plymouth, Rensselaer and Veedersburg. Unfortunately, it was not possible to obtain estimates from another subdistrict for a variety of reasons and consequently data were available from 11 subdistricts rather than the 12 originally intended.

At each subdistrict office a meeting was held, generally with the general foreman and two unit foremen. A total of 33 maintenance personnel were interviewed in the state. The meeting consisted simply of recording the service life and daily accomplishment estimates given by the foremen on blank forms similar to Tables 2 to 18 in this thesis for the various activities. It was believed that personal interview would obtain less ambiguous responses and a higher response rate than mailed questionnaires. It should be noted that the field personnel were extremely co-operative in every instance and were both knowledgeable and lucid in the discussions held. Care was taken to avoid asking leading questions and generally very little prompting was required to get numerical estimates with accompanying justification for the values given.

CHAPTER 6

ANALYSIS OF RESULTS

6.1 Computation of Service Life and Accomplishment Values

The results of the field survey of maintenance personnel were statistically analyzed. The mean and standard deviation for each cell in the matrix were calculated for every activity included in the survey. These values are tabulated in Tables 2 through 18 in this chapter.

The survey was also designed so that comparisons could be made between northern, central and southern subdistricts. The intention was to identify possible effects of climatic, topographic or other factors on the perception of unit foremen about the average service life or daily accomplishment values. The northern subdistricts were Fort Wayne, Bluffton, Rensselaer and Plymouth. The subdistricts of Veedersburg, Anderson and Ridgeville were designated to be central while Columbus, Bloomington, Petersburg and Branchville comprised the southern subdistricts sampled.

Calculations of service life and daily accomplishments for all activities within each stratum

were also performed. Analysis of variance or ANOVA tables were compiled to determine the source of variation between the regional strata. A total of 85 ANOVA tables were compiled. An F-test was carried out at the 95% and 90% confidence level to determine whether or not the means were equal. If the means were found to be equal, it was concluded that the regional or geographical factor was not significant. The F-values computed can be found in Appendix B.

If the means were found to be not equal, a Tukey Multiple Comparison Test was performed to determine the regional ranking. The level of significance used was generally 90%. All of the raw data were entered on the IBM-XT computer for permanent storage purposes, and neccessary manipulation of the data was performed using this machine.

6.2 Computation of Cost Information

An overall cost per accomplishment unit can be obtained simply by dividing the total cost of each activity by the related total number of accomplishment units. This figure is, of course, of interest, but does not reflect the variation in cost per unit as the accomplishment per day attained increases or decreases. Consequently, efforts were made to obtain a cost per production unit for each cell of each activity.

It is believed that this information will be more useful in determination of the most cost-effective treatment for a particular defect, as the road condition is taken into account. Also, the minimum, average and maximum values can be utilized to allow for influencing factors such as traffic volume, within each road condition bracket.

The approach taken was to obtain total costs, total labor costs, total accomplishments and total mandays for each activity from the Indiana Department of Highways computer records for 1985-1986 [2]. An estimate of the average manhours per day for each activity was obtained in the survey of maintenance personnel as can be seen in Tables 2 through 18. Using these values, an average labor cost per day for each activity was readily obtained. This cost was taken to be constant, regardless of the accomplishment attained. The remainder of the cost, namely fuel and materials, was taken to vary directly with the accomplishment attained.

In other words, a straight line relationship was assumed with labor cost being a constant and the slope of the line being equal to (Total Cost - Labor Cost) divided by total accomplishment units. Labor cost is taken to be constant as the same crew size is required to perform a given activity regardless of the number of accomplishment units of that activity attained. If shallow patching is taken as an example, the same crew size of 7 men is

required regardless of the amount of patching as the crew is assigned to patching at the beginning of the day for the whole day.

If the crew patches poor roads, it may put down around 7 tons of mix during the day. On a good road, however, the crew may only put down 3 tons of mix as the distressed locations are fewer and farther apart. Consequently, the total cost per ton of mix is greater on a good road. This is reflected in the relationship assumed where the material cost per ton (accomplishment unit) remains the same regardless of the number of tons placed but the labor cost per ton does vary. This is because the total labor cost is fixed so that the labor cost per ton increases as the number of tons placed decreases. This straight-line assumption is believed to be reasonable within the range of accomplishments found in this research for Indiana. The basic cost calculations can be found in Appendix C.

6.3 Shallow Patching (201)

There are four sub-divisions within this activity corresponding to the different possible materials used in patching. They are hot mix, cold mix, winter or fibre mix and fibre mix run through a Portapatcher. Each of these was treated as a seperate subject of interest with individual service life and accomplishments being obtained.

The effective service life of a patch was taken to be the time elapsed until more patching was necessitated at the location where the patch was placed. This approach was taken as it was pointed out by the maintenance personnel that although the material in the patch itself may remain in place for a considerable length of time, cracking and break-up at the edges of the patch may begin very rapidly and require more patching.

6.3.1 Hot Mix Patch

The information on hot mix patch service life and accomplishments is given in Table 2. This type of patching has consistently the highest estimate of effective service life. There are a number of reasons why this is so. Firstly, the material is usually of superior quality and more easily placed than the other three types. There is also the factor that hot mix is generally only available

between April and October as plant production is limited to these months. Consequently the climatic and road-base conditions are usually favorable for placement of the patch which naturally leads to better performance. The service life of a hot mix patch is very dependent on the roadway condition. An examination of the average values in Table 2 shows that the service life goes from 8.5 months on a poor road to 17.2 months on a fair road.

It was generally considered that a hot mix patch placed on a good road should last for the maintenance life of the road. This period was taken to be 60 months for the purposes of calculation. The accomplishments per day vary in an expected way, decreasing as the roadway condition improves and decreasing as the service life increases. This pattern is consistent for all four types of shallow patching.

The daily accomplishment decreases with improving roadway condition simply because there is less severe distress at any one location and distressed locations are further apart on a good road. There are two reasons why the service life and accomplishments vary inversely for a given road condition. Firstly, a location which yields a high daily accomplishment exhibits a large amount of distress. The source of this distress may be poor drainage, heavy traffic volumes etc., and undoubtedly this source will cause failure around the newly- patched

surface. Thus there is no cause-and-effect relationship between service life and daily accomplishments per se here; both simply reflect the effect of the distress source.

The second factor does reflect such a relationship, however. If more care and thoroughness is practised in placing the patch mix, the daily accomplishment will go down but this care will be reflected in an increased effective service life. These two factors combined explain the difference between minimum, average and maximum in accomplishment units for any given roadway condition. There was no statistically significant geographical factor present in the service life and daily accomplishment estimates except for the daily accomplishment value on a poor road where, with 90% confidence, the daily accomplishment in the central region is higher than in the south. There was no difference between actual average and attainable average for the hot mix patch estimates.

6.3.2 Cold Mix Patch

Cold patching material was considered by all personnel surveyed to be the poorest performer of the four. It can be seen from the results on Table 3 that most service life estimates were given in days rather than months. The primary factor for this is that the conditions under which it is placed make it very difficult for the patch to hold.

For example, cold mix is usually used in winter when no hot mix is available and consequently weather conditions are poor with the base being wet. Roadway condition does influence the service life estimates, but not to the extent seen in the hot mix estimates. The average service life estimate for a poor road was 0.3 months and this increased only to 0.7 months for a good road.

Other significant comments noted on patch life include the points that the cold mix is not stable and tends to shove and also that in some instances snowploughs will remove the material overnight. The only case where means differed significantly was for daily accomplishments on a poor road where the southern subdistricts were significantly lower, at the 90% confidence level, than the northern and central subdistricts. There was no difference in estimates between the actual average and attainable average for this activity.

6.3.3 Winter Mix Patch

Winter mix patch material is essentially a cold mix with polypropylene fibres added to produce greater stability and resistance to shoving. It is used under the same conditions as cold mix. Almost all personnel interviewed believed that this material was significantly better than the standard cold mix in its ability to stay in place. This belief is reflected in the service life values shown

in Table 4. For example, the average winter mix service life value ona poor road was 3.7 months compared to a value of 0.3 months for the cold mix patch. Maintenance personnel also believed that the winter mix was easier to break up and work with than the cold mix.

There was no significant geographical factor present except in the case of daily accomplishments on a poor road, where the southern subdistricts were significantly lower than the northern subdistricts in their estimates. There was no difference between the attainable average and actual average estimates for winter mix patching.

6.3.4 Winter Mix Patch using Portapatcher

A Portapatcher is basically a machine that heats the patching material so that it can be placed hot even during the winter. This heating process makes the material easier to handle and to place. The Portapatcher seems to be used primarily in the central and northern districts; only one of the four southern subdistricts sampled had used it regularly.

The foremen generally felt that the use of a Portapatcher does produce a longer service life than simply placing the mix cold; particularly as the roadway condition improves. A comparison of the values in Table 4 and Table 5 shows this trend clearly. For example, the

average service life value for a Portapatcher patch placed on a poor roadway is 5.3 months compared to 3.7 months for a winter mix patch. However, on a good road, the equivalent values are 23.1 months for a Portapatcher patch versus 5.8 months for a winter mix patch. Two of the four northern subdistricts were enthusiastic about the Portapatcher's usefulness and expressed the opinion that the heated patch material performs as well as hot mix.

It was also pointed out that in locations where flexibility and elasticity are important, e.g. on bridge decks, the heated fibre mix patch will perform more successfully than will a hot mix patch. However, a larger crewsize is required for Portapatcher-heated winter mix patching based on the average manhours per day. A problem mentioned by one subdistrict was that if the temperature in the Portapatcher becomes too high that the fibres will burn thus making the material useless. The personnel in that subdistrict believed that the use of hot boxes was preferable. However, this problem was not mentioned at the other subdistricts sampled. The geographical factor was not significant in this case, and there was no difference between actual average and attainable average values.

6.4 Premix Levelling (203)

Premix levelling or wedging involves placement of bituminous mixtures to correct depressions and rutting. A

number of the subdistricts indicated that this activity is now primarily carried out by contract rather than by I.D.O.H. personnel. However, most subdistricts had sufficient experience to estimate service life and daily accomplishments.

The results of the survey for this activity are contained in Table 6. These estimates follow an expected pattern for similar reasons to those mentioned in the discussion on patching. The primary reason given for early failure of wedging was the roadway surface not being tacked properly prior to application of the bituminous mixture. This activity was also one of the few where the attainable average value differed from the actual average value.. As previously explained, this value is used when the maintenance personnel want to distinguish between the average value actually obtained on the road and the value that could be obtained given better manpower, equipment or other reasons.

In the case of premix levelling, a distinction was frequently made between the service life obtained when the mix was spread and levelled by grader as opposed to using a paving machine. It was felt that the paver produces a more uniform, better-riding and longer-lasting surface. A practical reason some subdistricts spread premix material using a grader is that a paver must be hired from a contractor and is frequently unavailable when required.

In those subdistricts where pavers are used by the maintenance crews, no difference exists between the actual average and attainable average values. The geographical factor was significant for this activity. The central subdistricts had a lower effective service life mean estimate than the northern or southern subdistricts on both poor and good roads, with 90% confidence. The means were not significantly different for fair roadway condition.

6.5 Full Width Shoulder Seal (204)

This operation involves seal coating of a paved shoulder to prevent surface deterioration and to correct surface deficiencies. When the shoulder condition is poor, the general consensus of opinion was that a shoulder seal was not an appropriate treatment as it provides no structural support. This belief is reflected in the results tabulated in Table 7. The appropriate activity was deemed to be a rebuilding of the shoulder (213), followed by surface treatment.

It is of interest to note that the service life and daily accomplishments vary directly in this activity. The explanation is that the unit of accomplishment is foot-miles and a shoulder at the lower end of the fair shoulder range will require more work (and hence less miles covered) and break up faster than one at the upper end of

the range. Thus, for a fair roadway condition, the effective service life ranges from a minimum of 24 months to a maximum of 37.2 months while accomplishments vary from 65.0 footmiles for the minimum value to 83.5 footmiles for the maximum value. Consequently, it is again the source of the deficiency that establishes the relationship between accomplishments and service life.

The major factor that influences the daily accomplishment obtained is the width of the shoulder to be sealed. Obviously a much higher accomplishment in foot-miles will be obtainable on a 10 foot shoulder rather than on a 3 foot one. There was not a significant geographical factor evident in the service life or daily accomplishment estimates given nor was there a difference between actual average and attainable average values.

6.6 Seal Coating (205)

There are several possible types of seal coat treatments including chip seals, sand seals, slurry seals and fog seals. However, the IDOH only makes use of chip seals and sand seals in routine maintenance.

6.6.1 Chip Seal

This activity consists of coating full width roadway sections with hot bituminous material and covering with #11 or #12 stone. One factor that can influence the

service life obtained is the type of stone used in the surfacing operation; limestone chips were believed to be much preferable to pea gravel.

The service life and daily accomplishment pattern as seen in Table 8 is similar to that seen in the discussion of Full Width Shoulder Seal. Existing roadway condition does affect the srvice life estimates, with the average ranging from 26.4 months for a poor roadway condition to 48.0 months for a good roadway condition. The major factor governing the daily accomplishment was believed to be the haulage distance for both the bituminous material and aggregate rather than the condition of the roadway surface itself. There was not a significant geographical factor present in the service life or daily accomplishment estimates obtained, nor was there a difference between actual and attainable average values.

6.6.2 Sand Seal

There was a total of 5 subdistricts interviewed with sufficient experience to estimate sand seal service life values, although a number of the other subdistricts have begun to utilize this activity in the last 2 to 3 years. Personnel generally believed that the sand seal was not effective for a poor roadway condition. On a poor surface, the sand seal does not prevent continued

deterioration or seal cracks for any appreciable length of time.

When the road condition was fair or good, the consensus of opinion was that a sand seal is effective in sealing cracks and will contribute substantially to the longevity of the road life. By comparing Tables 8 and 9 it can be seen that a chip seal operation is believed to give a longer effective service life. For example, the average service life on a good road is 48.0 months for a chip seal versus an estimated 21.6 months for a sand seal operation. One subdistrict reported that the sand seal was very effective when placed over a "fatted" surface, i.e. one still containing a lot of asphalt whereas the chip seal was better suited to dried-out pavements. The same trends in service life and accomplishments observed in the shoulder seal activity are again evident here, with service life and daily accomplishments varying directly. The mean estimates of service life and daily accomplishment did not differ significantly by region. There was no difference between actual average and attainable average values, indicating that availability of resources and required equipment is not seen to be a problem for this activity.

6.7 Filling Longitudinal Cracks and Joints (206)

This activity involves the filling of longitudinal cracks and joints with liquid bituminous sealant after cleaning of the joint. The most common method of joint cleaning is with an air compressor using a wand to blow out the accumulated debris. An alternative method is using a crack router attached to a tractor but this operation comes under activity 219, Other Roadway and Shoulder Maintenance and hence is not considered here.

An examination of Table 10 shows that there is not a very large differente between maximum and minimum service life estimates for any given roadway condition. For a poor joint condition, the estimates range from a minimum of 17.7 months to a maximum of 26.2 months. In fact, a number of subdistricts did not believe that there was any appreciable difference at all. However, the estimates do vary substantially as the roadway condition changes from poor to good with the average service life value going from 22.5 to 34.9 months. Accomplishments also vary substantially with roadway condition, ranging from 6.3 linear miles for a poor condition to 10.2 linear miles for a good condition. This is to be expected as more linear miles, the accomplishment unit, can be attained on a good road than on a poor one. There was no statistically significant geographical factor obvious in the estimates obtained from the maintenance personnel. There was no

difference between actual and attainable average values for this activity.

6.8 Filling Cracks (207)

The purpose of this activity is to clean and fill cracks in bituminous and concrete pavements. An examination of Table 10 shows a marked difference between maximum and minimum for each roadway condition, in contrast with activity 206. For example, the service life for a poor road more than doubles in going from a minimum of 8.2 months to a maximum of 17.4 months. An analysis of the data by region shows no significant differences in service life estimates except for poor roadway condition where the central region estimates are lower, with 90% confidence, than those of the north and south. There is no ready explanation as to why this should be so. However, in two of the central subdistricts it was believed that crack sealing a poor surface was tantamount to "pouring money away" and perhaps unduly low estimatea were given to emphasise this point.

The accomplishments in lane-miles per day change very definitely with the condition of the roadway; the average estimate for a poor roadway was 1.5 lane miles compared to a value of 4.5 lane miles for a good roadway condition. The number of lane-miles sealed will be lower as the condition of the road deteriorates, i.e. more sealing will

be required for a badly-cracked roadway. An interesting sidelight on the use of a sand seal versus a chip seal is that it was believed that crack sealing could be subsequently carried out effectively on a chip seal treatment whereas the bituminous material would not hold on a sand seal surface. There was no difference between the actual and attainable average estimates.

6.9 Spot Repair of Unpaved Shoulders (210)

Activity 210 involves the repair of small areas of unpaved shoulders by addition of aggregate and reshaping of the shoulder. The results obtained are tabulated in Table 12. No significant differences were found in the service life estimates given by the various subdistricts except for the minimum values which were significantly lower, with 90% confidence, for the southern region. This may be explained by the topography in Southern Indiana which is very hilly and the locations that yield the lowest service lifes are on sloped curves.

The main factor influencing the service life of this activity was believed to be rainfall in combination with high roadway gradients. The significance of curves here is that in general this is where most of the traffic encroachment onto the shoulder will take place. Service life and daily accomplishments vary inversely in this case because the accomplishment unit is tons of aggregate and

the worst locations require more aggregate more frequently than areas less suceptible to erosion for a given shoulder condition. Thus, for a poor roadway condition, the average service life estimate is 4.7 months with an associated accomplishment of 46.4 tons of aggregate whereas for a fair roadway condition the service life estimate rises to 8.3 months and the accomplishment falls to 30.5 tons.

6.10 Blading Shoulders (211)

Activity 211 involves the blading and reshaping of unpaved shoulders. The survey results for this activity are shown in Table 13. There is no substantial geographical factor at play in the service life and daily accomplishment estimates obtained from the maintenance personnel. The daily accomplishment unit is in shoulder miles and there is a direct relationship between service life and accomplishments. The poorest locations yield both the lowest service life and lowest daily accomplishment estimates. The maintenance personnel interviewed felt that in this activity, the use of a dump truck with scraper or underblade attached produced the most satisfactory results. There was no difference between actual and attainable average estimates for this activity.

6.11 Clipping Shoulders (212)

The purpose of this operation is to remove excess growth from unpaved shoulders and to ensure adequate shoulder slope. For a given shoulder condition, the southern subdistricts are significantly under the overall average while the northern subdistricts are significantly above it for both service life and accomplishment estimates. Logically, the milder climate in Southern Indiana encourages vegetation growth more so than in the north. There is not much variation in service life estimates as the shoulder condition changes from poor to fair but the accomplishment estimates do vary substantially. For example, the average service life estimates only changes from 37.1 to 43.1 months but the accomplishments go from 1.9 to 3.2 shoulder miles. Clipping Shoulders is another activity where the attainable average value differs from the actual average as can be seen in Table 14. A number of subdistricts distinguished between the daily accomplishments obtainable using a front end loader and what was variously described as a dirt loader, belt loader or travel loader. Generally it was considered that the shoulder miles attained per day could be increased using the latter type of loader. For a poor shoulder condition, the average accomplishment is 1.9 months while the attainable average increases to 2.2 months. The service life estimate remains the same, 37.1 months, for both

average values. Factors which influence the accomplishment obtained include the amount of material to be cut and loaded and the haulage distance to dump.

6.12 Recondition Unpaved Shoulders (213)

This activity involves the addition of aggregate and reshaping of unpaved shoulders for continuous lengthy sections of shoulder as opposed to activity 210 which is carried out at isolated locations. None of the four southern subdistricts sampled had sufficient experience to estimate service life or accomplishment values. The service life and daily accomplishment estimates obtained for the central region were significantly lower, with 95% confidence, than the northern values. A possible explanation is that the northern subdistricts tend to seal or oil the rebuilt shoulder in the same year which should lead to a longer service life.

An examination of Table 15 shows that in general there was little variation in the service life or daily accomplishments for a given shoulder condition. In general, the main variable influencing accomplishment was felt to be the aggregate haulage distance. There was no difference between actual and attainable average estimates for this activity.

6.13 Clean And Reshape Ditches (231)

Cleaning and reshaping ditches comprises the excavation of dirt and debris from roadside ditches using a gradall for the purpose of restoring proper ditch slope for adequate drainage. Geography plays a major role in the estimates obtained. The central and northern subdistricts were not significantly different in their service life estimates but the southern subdistricts estimates were lower, with 90% confidence, for both service life and daily accomplishments.

This is a reasonable trend as topography and soil conditions should play an important role in the rapidity and extent of ditch blockage. For instance, in areas with steep hills, heavy rainfall and poor soil conditions, the service life of Activity 231 is low. For the same reason, the daily accomplishment, measured in linear feet of ditch, is also low in such areas, generally around 400 feet.

Another factor that influences daily accomplishment obtained is the distance neccessary to haul material to dump. An interesting point that was often repeated in discussion with the maintenance personnel was that the daily production can be very misleading. In a ditch that is badly clogged up with debris, it may be necessary to make two or three passes with the excavator to restore an

adequate cross-section. However, this extra work does not show up in the daily record. This is the basic reason why an examination of Table 16 shows such a large variation in daily accomplishments as the ditch condition changes. There was no difference between actual and attainable average values for cleaning and reshaping ditches.

6.14 Pipe Replacement (233)

The variable in pipe replacement is the depth of excavation to pipe. A small depth is equivalent to a 3 foot excavation, one suitable for placing a 15" pipe. A medium depth is 4 feet, required for an 18" pipe. Finally, a large depth is taken to be 6 feet or more. There was little variation in the longevity expected and obtained for the pipes once placed with most subdistricts anticipating 15 to 20 years or more as can be seen in Table 17. However, in one subdistrict which is located in a mining area, the effect of cuprous water in corroding the pipes led to lower estimates of effective service life in the region of 5 to 15 years.

The daily accomplishment obtained was almost identical everywhere. The maximum number of locations attainable in one day was 2 for a small required excavation depth, but this was with the proviso that the locations be close together. In general, one location per day was expected with slightly less than one per day (i.e.

one or two hours of overtime being necessary) for the large (6´) excavation depth.

There was some variation in the method used to cover the excavated trench. Some subdistricts backfill and place the asphalt surfacing on the same day for a completed job. Other subdistricts backfill and cover with #73 stone. Traffic is allowed to compact the backfill for one or two weeks before the asphalt surfacing is placed. There was no geographical trend evident in determining which method is used. There was no significant regional trend present in the effective service life and daily accomplishment estimates given, nor was there any difference between actual and attainable average estimates.

6.15 Motor Patrol Ditching (234)

This activity involves ditching as in Activity 231, but using a motor patrol rather than a gradall to do the cutting. There was much discussion as to the merits and de-merits of performing a 234 versus a 231 activity. In one southern subdistrict, motor patrol ditching is not carried out at all because it is believed to be impossible to use a motor patrol on the hilly terrain with heavily blocked ditches. A common opinion expressed was that motor patrol ditching can only be carried out when weather conditions are favourable, particularly in July and

August. The motor patrol was believed to be suitable for use in sandy soils but not in heavy, clayey soils with steep ditches.

Another valid use of the motor patrol in ditching suggested by a number of subdistricts was in the medians of multi-lane highways and on flat, wide ditches. However, the consensus of subdistrict opinion was also that the use of the gradall in 231 produces a better, more rounded and longer-lasting ditch cross-section than the motor patrol. For example, the average service life for a fair ditch condition is 45.3 months for Activity 231 versus a value of 38.3 months for Activity 234.

A comparison of the daily accomplishments contained in Tables 17 and 18 shows that motor patrol ditching, measured in ditch miles, covers much greater daily distances than gradall ditching which is measured in feet. The average daily accomplishments on a poor ditch is 1.3 miles for a motor patrol operation versus 696 linear feet for Activity 231. The principal explanation for this is the application of motor patrol ditching in practise being limited to wide areas where few obstructions are present. The main factor that governs the daily accomplishment attained is the distance required to haul the debris from the ditch to a designated dump site. There was not a significant geographical factor present in the service life or daily accomplishment estimates obtained for motor

patrol ditching. There was no difference between actual and attainable average values for this activity.

Table 2
Hot Mix Patch
Service Life and Daily Accomplishments

SHALLOW PATCHING (201) - HOT MIX				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 2.8 Dev=2.5 A.P.D= 7.7 Dev=2.7 C.P.U=82.2	S.L.= 8.5 Dev=3.2 A.P.D= 7.2 Dev=1.5 C.P.U=85.2	S.L.= 12.5 Dev=4.2 A.P.D= 6.7 Dev=8.9 C.P.U=88.7	S.L.= 8.5 Dev=3.2 A.P.D= 7.2 Dev=1.5 C.P.U=85.2
Fair	S.L.= 9.9 Dev=5.5 A.P.D= 4.4 Dev=0.6 C.P.U=115	S.L.= 17.2 Dev=6.8 A.P.D= 4.2 Dev=0.8 C.P.U=119	S.L.= 23.7 Dev=8.9 A.P.D= 4.2 Dev=1.4 C.P.U=119	S.L.= 17.2 Dev=6.8 A.P.D= 4.2 Dev=0.8 C.P.U=119
Good	S.L.= 36.0 Dev =21.2 A.P.D= 3.0 Dev=0.6 C.P.U=151	S.L.= 53.4 Dev =12.8 A.P.D= 2.8 Dev=0.5 C.P.U=159	S.L.= 55.2 Dev =11.6 A.P.D= 2.5 Dev=0.8 C.P.U=174	S.L.= 53.4 Dev= 12.8 A.P.D=2.8 Dev=0.5 C.P.U=159

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Mix)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 50

N of Observations = 10

Table 3
Cold Mix Patch
Service Life And Daily Accomplishments

SHALLOW PATCHING (201) - COLD MIX				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 0.2 Dev= 0.0 A.P.D= 8.9 Dev=3.0 C.P.U=79.4	S.L.= 0.3 Dev=0.1 A.P.D= 7.1 Dev=2.6 C.P.U=89.0	S.L.= 0.7 Dev=0.8 A.P.D= 5.5 Dev= 2.2 C.P.U=103	S.L.= 0.3 Dev=0.1 A.P.D= 7.1 Dev= 2.6 C.P.U=89.0
Fair	S.L.= 0.2 Dev=0.4 A.P.D= 4.7 Dev=1.3 C.P.U=113	S.L.= 0.6 Dev= 0.5 A.P.D= 3.9 Dev=1.2 C.P.U=128	S.L.= 1.0 Dev=0.9 A.P.D= 3.3 Dev=1.1 C.P.U=144	S.L.= 0.6 Dev=0.5 A.P.D= 3.9 Dev=1.2 C.P.U=128
Good	S.L.= 0.3 Dev=0.2 A.P.D= 3.2 Dev=0.9 C.P.U=147	S.L.= 0.7 Dev=0.7 A.P.D= 2.6 Dev=0.8 C.P.U=172	S.L.= 1.2 Dev=1.0 A.P.D= 2.2 Dev=0.7 C.P.U=195	S.L.= 0.7 Dev=0.7 A.P.D= 2.6 Dev=0.8 C.P.U=172

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Mix)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 50

N of Observations = 11

Table 4
Winter Mix Patch
Service Life And Daily Accomplishments

SHALLOW PATCHING (201) - WINTER MIX				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 1.0 Dev=1.6 A.P.D= 8.0 Dev=2.7 C.P.U=78.5	S.L.= 3.7 Dev=4.1 A.P.D= 6.7 Dev=2.1 C.P.U=86.7	S.L.= 3.8 Dev= 4.0 A.P.D= 5.4 Dev=1.6 C.P.U=98.9	S.L. =3.7 Dev=4.1 A.P.D= 6.7 Dev=2.1 C.P.U=86.7
Fair	S.L.= 3.1 Dev=3.7 A.P.D= 4.6 Dev=1.3 C.P.U=110	S.L.= 5.0 Dev=5.8 A.P.D= 4.0 Dev=1.1 C.P.U=121	S.L.= 5.9 Dev=6.2 A.P.D= 3.3 Dev=1.0 C.P.U=139	S.L.= 5.0 Dev=5.8 A.P.D=4.0 Dev=1.1 C.P.U=121
Good	S.L.= 3.3 Dev=3.6 A.P.D= 3.3 Dev=0.9 C.P.U=139	S.L.= 5.8 Dev=7.3 A.P.D= 2.7 Dev=0.8 C.P.U=162	S.L.= 6.8 Dev=7.5 A.P.D= 2.4 Dev=0.6 C.P.U=177	S.L.= 5.8 Dev=7.3 A.P.D= 2.7 Dev=0.8 C.P.U=162

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Mix)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 50

N of Observations = 10

Table 5
Portapatcher Patch
Service Life and Daily Accomplishments

SHALLOW PATCHING (201) - USING PORTAPATCHER				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 1.3 Dev=1.3 A.P.D= 6.5 Dev=1.9 C.P.U=97.6	S.L.= 5.3 Dev=4.4 A.P.D= 5.4 Dev=1.5 C.P.U=110	S.L.= 7.3 Dev=6.5 A.P.D= 4.3 Dev=1.4 C.P.U=129	S.L.= 5.3 Dev=4.4 A.P.D= 5.4 Dev=1.5 C.P.U=110
Fair	S.L.= 6.6 Dev=6.5 A.P.D= 4.8 Dev=0.6 C.P.U=119	S.L.= 8.9 Dev=7.9 A.P.D= 3.8 Dev=0.8 C.P.U=141	S.L.= 11.6 Dev=11.2 A.P.D= 2.8 Dev=0.8 C.P.U=179	S.L.= 8.9 Dev=7.9 A.P.D= 3.8 Dev=0.8 C.P.U=141
Good	S.L.= 14.7 Dev=22.7 A.P.D= 3.1 Dev=0.7 C.P.U=165	S.L.= 23.1 Dev=28.8 A.P.D= 2.7 Dev=0.7 C.P.U=184	S.L.= 24.1 Dev= 28.1 A.P.D= 2.3 Dev=0.8 C.P.U=210	S.L.= 23.1 Dev=28.8 A.P.D= 2.7 Dev=0.7 C.P.U=184

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Mix)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 59

N of Observations = 6

Table 6
Premix Levelling
Service Life and Daily Accomplishments

PREMIX LEVELLING (203)				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.=17.1 Dev=9.4 A.P.D=151 Dev=51.7 C.P.U=35.2	S.L.=24.9 Dev=11.2 A.P.D=120 Dev=38.7 C.P.U=36.3	S.L.=30.9 Dev=14.9 A.P.D=87.9 Dev=24.8 C.P.U=38.2	S.L.=26.6 Dev=14.6 A.P.D=120 Dev=38.7 C.P.U=36.3
Fair	S.L.=29.1 Dev=9.4 A.P.D=105 Dev=44.4 C.P.U=37.0	S.L.=34.3 Dev=9.0 A.P.D=88.6 Dev=36.6 C.P.U=38.1	S.L.=41.1 Dev=13.6 A.P.D=69.3 Dev=26.2 C.P.U=40.1	S.L.=37.7 Dev=12.4 A.P.D=88.6 Dev=36.6 C.P.U=38.1
Good	S.L.=36.0 Dev=6.9 A.P.D=65.7 Dev=38.7 C.P.U=40.6	S.L.=47.1 Dev=10.0 A.P.D=55.0 Dev=34.8 C.P.U=42.4	S.L.=49.7 Dev=10.8 A.P.D=47.9 Dev=31.6 C.P.U= 44.1	S.L.=49.7 Dev=10.8 A.P.D=55.0 Dev=34.8 C.P.U=42.4

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Premix)

Dev = Standard Deviation about Mean Estimate

C.P.U. = Cost per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 88

N of Observations = 7

Table 7
Full Width Shoulder Seal
Service Life and Daily Accomplishments

	FULL WIDTH SHOULDER SEAL (204)			
	Effective Service Life			
Shoulder Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 0 A.P.D= 0	S.L.= 0 A.P.D= 0	S.L.= 0 A.P.D= 0	S.L.= 0 A.P.D= 0
Fair	S.L.= 24.0 Dev=9.4 A.P.D=65.0 Dev=16.7 C.P.U=169	S.L.= 30.6 Dev=10.0 A.P.D=73.5 Dev=16.8 C.P.U=167	S.L.= 37.2 Dev=9.7 A.P.D=83.5 Dev=18.6 C.P.U=165	S.L.= 30.6 Dev=10.0 A.P.D=73.5 Dev=16.8 C.P.U=167
Good	S.L.=31.2 Dev=12.9 A.P.D=65.5 Dev=15.4 C.P.U=169	S.L.=39.6 Dev=11.7 A.P.D=74.5 Dev=14.0 C.P.U=167	S.L.=45.0 Dev=10.3 A.P.D=85.0 Dev=14.3 C.P.U=165	S.L.=39.6 Dev=11.7 A.P.D=74.5 Dev=14.0 C.P.U=167

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Foot Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 155

N of Observations = 10

Table 8
Chip Seal
Service Life and Daily Accomplishments

SEAL COATING (205) - CHIP SEAL				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 24.6 Dev=10.8 A.P.D= 5.0 Dev=1.7 C.P.U=1436	S.L.= 26.4 Dev=9.5 A.P.D= 6.3 Dev=2.0 C.P.U=1386	S.L.= 32.4 Dev=12.7 A.P.D= 7.8 Dev=2.9 C.P.U=1349	S.L.= 26.4 Dev=9.5 A.P.D= 6.3 Dev=2.0 C.P.U=1386
Fair	S.L.= 31.8 Dev=9.0 A.P.D= 5.5 Dev=1.6	S.L.= 37.4 Dev=10.5 A.P.D= 6.8 Dev=1.7	S.L.= 45.6 Dev=9.5 A.P.D= 8.5 Dev=2.2	S.L.= 37.4 Dev=10.5 A.P.D= 6.9 Dev=1.7
Good	S.L.= 37.8 Dev=8.1 A.P.D= 6.2 Dev=1.7 C.P.U=1389	S.L.= 48.0 Dev=8.0 A.P.D= 7.5 Dev=1.7 C.P.U=1355	S.L.= 55.2 Dev=6.2 A.P.D= 9.1 Dev=2.0 C.P.U=1327	S.L.= 48.0 Dev=8.0 A.P.D= 7.5 Dev= 1.7 C.P.U=1355

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Lane Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 168

N of Observations = 10

Table 9
Sand Seal
Service Life And Daily Accomplishments

SEAL COATING (205) - SAND SEAL				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 0 A.P.D=0	S.L.= 0 A.P.D=0	S.L.= 0 A.P.D=0	S.L.=0 A.P.D=0
Fair	S.L.=14.4 Dev=6.8 A.P.D=6.2 Dev=1.6 C.P.U=1389	S.L.=15.6 Dev=6.8 A.P.D=8.2 Dev=2.0 C.P.U=1341	S.L.=20.4 Dev=5.4 A.P.D=10.8 Dev=2.8 C.P.U=1305	S.L.=15.6 Dev=6.8 A.P.D=8.2 Dev= 2.0 C.P.U=1341
Good	S.L.=19.2 Dev=6.6 A.P.D=6.2 Dev=1.6 C.P.U=1389	S.L.=21.6 Dev=6.8 A.P.D=8.2 Dev=2.0 C.P.U=1341	S.L.=28.8 Dev=6.6 A.P.D=10.8 Dev=2.8 C.P.U=1305	S.L.=21.6 Dev=6.8 A.P.D=8.2 Dev=2.0 C.P.U=1341

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Lane Miles)

Dev = Standard Deviation about Sample Mean

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 168

N of Observations = 5

Table 10
Sealing Longitudinal Cracks and Joints
Service Life and Daily Accomplishments

SEALING LONGITUDINAL CRACKS AND JOINTS (206)				
	Effective Service Life			
Joint Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 17.7 Dev=9.3 A.P.D= 5.9 Dev=2.2 C.P.U=136	S.L.= 22.5 Dev=11.8 A.P.D= 6.3 Dev=2.1 C.P.U=131	S.L.= 26.2 Dev=12.9 A.P.D= 6.7 Dev=2.2 C.P.U=127	S.L.= 22.5 Dev=11.8 A.P.D= 6.3 Dev=2.1 C.P.U=131
Fair	S.L.=25.6 Dev=11.4 A.P.D= 8.0 Dev=2.4 C.P.U=115	S.L.=29.5 Dev=9.8 A.P.D= 8.4 Dev=2.4 C.P.U=113	S.L.=33.3 Dev=9.8 A.P.D= 9.1 Dev=2.4 C.P.U=108	S.L.=29.5 Dev=9.8 A.P.D= 8.4 Dev=2.4 C.P.U=113
Good	S.L.= 31.6 Dev=9.7 A.P.D=9.8 Dev=3.9 C.P.U=105	S.L.=34.9 Dev=8.0 A.P.D=10.2 Dev=3.8 C.P.U=103	S.L.=38.2 Dev=10.5 A.P.D=10.9 Dev=3.7 C.P.U=100	S.L.=34.9 Dev=8.0 A.P.D=10.2 Dev=3.8 C.P.U=103

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Linear Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 72

N of Observations = 11

Table 11
Sealing Cracks
Service Life and Daily Accomplishments

SEALING CRACKS (207)				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 8.2 Dev=4.5 A.P.D= 1.2 Dev=0.4 C.P.U=607	S.L.= 13.1 Dev=7.1 A.P.D= 1.5 Dev=0.6 C.P.U=508	S.L.= 17.4 Dev=11.6 A.P.D= 1.8 Dev=0.5 C.P.U=441	S.L.= 14.2 Dev=9.4 A.P.D= 1.5 Dev=0.6 C.P.U=508
Fair	S.L.= 13.6 Dev=3.9 A.P.D= 2.8 Dev=1.3 C.P.U=322	S.L.= 19.9 Dev=5.7 A.P.D= 3.0 Dev=0.9 C.P.U=308	S.L.= 24.5 Dev=8.3 A.P.D= 3.1 Dev=0.8 C.P.U=302	S.L.= 21.0 Dev=7.5 A.P.D= 3.0 Dev=0.9 C.P.U=308
Good	S.L.= 20.7 Dev=9.4 A.P.D= 4.1 Dev=1.8 C.P.U=255	S.L.= 26.5 Dev=9.0 A.P.D= 4.5 Dev=1.6 C.P.U=242	S.L.= 31.6 Dev=8.1 A.P.D= 4.9 Dev=1.6 C.P.U=231	S.L.= 27.5 Dev=9.4 A.P.D=4.5 Dev=1.6 C.P.U=242

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Lane Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 88

N of Observations = 11

Table 12
Spot Repair of Unpaved Shoulders
Service Life and Daily Accomplishments

SPOT REPAIR OF UNPAVED SHOULDERS (210)				
	Effective Service Life			
Shoulder Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 3.0 Dev=1.8 A.P.D=51.4 Dev=21.2 C.P.U=11.8	S.L.= 4.7 Dev=3.6 A.P.D=46.4 Dev=15.3 C.P.U=12.5	S.L.= 6.2 Dev=5.0 A.P.D=41.8 Dev=12.5 C.P.U=13.3	S.L.= 4.7 Dev=3.6 A.P.D=46.4 Dev=15.3 C.P.U=12.5
Fair	S.L.= 6.3 Dev=3.9 A.P.D=32.7 Dev=9.8 C.P.U=15.5	S.L.= 8.3 Dev=3.7 A.P.D=30.5 Dev=8.2 C.P.U=16.2	S.L.= 10.9 Dev=3.9 A.P.D=27.7 Dev=9.3 C.P.U=17.3	S.L.= 8.3 Dev=3.7 A.P.D=30.5 Dev=8.2 C.P.U=16.2

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Tons of Aggregate)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 48

N of Observations = 11

Table 13
Blading Shoulders
Service Life and Daily Accomplishments

BLADING SHOULDERS (211)				
	Effective Service Life			
Shoulder Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 2.7 Dev=2.3 A.P.D=10.2 Dev=1.1 C.P.U=19.2	S.L.= 4.4 Dev=4.1 A.P.D=10.6 Dev=1.3 C.P.U=18.5	S.L.= 4.8 Dev=4.7 A.P.D=11.3 Dev=2.2 C.P.U=17.5	S.L.= 4.4 Dev=4.1 A.P.D=10.6 Dev=1.3 C.P.U=18.5
Fair	S.L.= 5.7 Dev=3.5 A.P.D=12.4 Dev=2.3 C.P.U=16.2	S.L.= 7.2 Dev=4.0 A.P.D=13.2 Dev=2.2 C.P.U=15.3	S.L.= 7.8 Dev=4.2 A.P.D=14.4 Dev=2.9 C.P.U=14.2	S.L.= 7.2 Dev=4.0 A.P.D=13.2 Dev=2.2 C.P.U=15.3

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Shoulder Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 24

N of Observations = 11

Table 14
Clipping Unpaved Shoulders
Service Life and Daily Accomplishments

CLIPPING UNPAVED SHOULDERS (212)				
	Effective Service Life			
Shoulder Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 33.3 Dev=14.0 A.P.D= 1.5 Dev=0.9 C.P.U=372	S.L.= 37.1 Dev=111.3 A.P.D= 1.9 Dev=0.9 C.P.U=306	S.L.= 42.5 Dev=10.2 A.P.D= 2.3 Dev=1.2 C.P.U=262	S.L.= 37.1 Dev=11.3 A.P.D= 2.2 Dev=1.3 C.P.U=271
Fair	S.L.=39.3 Dev=17.0 A.P.D= 2.8 Dev=1.2 C.P.U=225	S.L.= 43.1 Dev=13.6 A.P.D= 3.2 Dev=1.0 C.P.U=204	S.L.= 47.5 Dev=10.9 A.P.D= 3.7 Dev=1.4 C.P.U=184	S.L.= 43.1 Dev=13.6 A.P.D= 3.5 Dev=1.1 C.P.U=191

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Shoulder Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 66

N of Observations = 11

Table 15
Recondition Unpaved Shoulders
Service Life and Daily Accomplishments

RECONDITION UNPAVED SHOULDERS (213)				
	Effective Service Life			
Shoulder Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 36.0 Dev=21.5 A.P.D= 3.3 Dev=1.2 C.P.U=929	S.L.= 38.0 Dev=19.2 A.P.D= 3.4 Dev=1.1 C.P.U=920	S.L.= 38.0 Dev=19.2 A.P.D= 3.4 Dev=1.1 C.P.U=920	S.L.= 38.0 Dev=19.2 A.P.D= 3.4 Dev=1.1 C.P.U=920
Fair	S.L.= 46.0 Dev=15.9 A.P.D= 4.5 Dev= 1.1 C.P.U=854	S.L.= 46.0 Dev=15.9 A.P.D= 4.5 Dev= 1.1 C.P.U=854	S.L.= 46.0 Dev=15.9 A.P.D= 4.5 Dev= 1.1 C.P.U=854	S.L.= 46.0 Dev=15.9 A.P.D= 4.5 Dev= 1.1 C.P.U=854

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Shoulder Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 130

N of Observations = 6

Table 16
Clean and Reshape Ditches
Service Life and Daily Accomplishments

CLEAN AND RESHAPE DITCHES (231)				
	Effective Service Life			
Ditch Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 28.6 Dev= 17.6 A.P.D=546 Dev= 180.9 C.P.U=0.96	S.L.= 30.8 Dev= 17.2 A.P.D=696 Dev= 269.7 C.P.U=0.79	S.L.= 34.4 Dev= 16.6 A.P.D=846 Dev= 461.2 C.P.U=0.69	S.L.= 30.8 Dev= 17.2 A.P.D=696 Dev= 269.7 C.P.U=0.79
Fair	S.L.= 42.7 Dev= 425.8 A.P.D=1082 Dev= 419.1 C.P.U=0.59	S.L.= 45.3 Dev= 369.8 A.P.D=1255 Dev= 419.8 C.P.U=0.53	S.L.=48.0 Dev= 316.8 A.P.D=1436 Dev= 454.5 C.P.U=0.49	S.L.= 45.3 Dev= 369.8 A.P.D=1255 Dev= 419.8 C.P.U=0.53

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Linear Feet of Ditch)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 58

N of Observations = 11

Table 17
Pipe Replacement
Service Life and Daily Accomplishments

PIPE REPLACEMENT (233)				
	Effective Service Life			
Depth to Pipe	Minimum	Average	Maximum	Attainable Average
Small	S.L.= 15.2 Dev=4.8 A.P.D= 1.0 Dev= 0 C.P.U=1434	S.L.= 17.0 Dev=3.3 A.P.D= 1.0 Dev= 0 C.P.U=1434	S.L.= 19.1 Dev=2.0 A.P.D= 2.0 Dev= 0 C.P.U=1214	S.L.= 17.0 Dev=3.3 A.P.D= 1.0 Dev= 0 C.P.U=1434
Medium	S.L.= 16.4 Dev=3.9 A.P.D= 1.0 Dev= 0 C.P.U=1434	S.L.= 17.3 Dev=2.6 A.P.D= 1.0 Dev=0 C.P.U=1434	S.L.= 19.1 Dev=2.0 A.P.D=1.0 Dev= 0 C.P.U=1434	S.L.=17.3 Dev=2.6 A.P.D= 1.0 Dev=0 C.P.U=1434
Large	S.L.= 16.4 Dev=3.9 A.P.D= 0.9 Dev= 0 C.P.U=1483	S.L.= 17.3 Dev=2.6 A.P.D= 0.9 Dev= 0 C.P.U=1483	S.L.= 19.1 Dev=2.0 A.P.D= 0.8 Dev= 0 C.P.U=1544	S.L.=17.3 Dev=2.6 A.P.D= 0.9 Dev= 0 C.P.U=1483

S.L. = Service Life (Years)

A.P.D = Accomplishments Per Day (Lineal Feet)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 63

N of Observations = 11

Table 18
Motor Patrol Ditching

MOTOR PATROL DITCHING (234)				
	Effective Service Life			
Ditch Condition	Minimum	Average	Maximum	Attainable Average
Poor	S.L.= 28.9 Dev=16.2 A.P.D= 1.0 Dev=0.5 C.P.U=550	S.L.= 29.8 Dev=17.1 A.P.D= 1.3 Dev=0.6 C.P.U=441	S.L.= 30.5 Dev=18.4 A.P.D= 1.7 Dev=1.4 C.P.U=355	S.L.= 29.8 Dev=17.1 A.P.D= 1.3 Dev=0.6 C.P.U=441
Fair	S.L.= 36.0 Dev=14.3 A.P.D= 1.7 Dev=1.0 C.P.U=355	S.L.= 38.3 Dev=14.3 A.P.D= 2.0 Dev=0.9 C.P.U=313	S.L.= 42.8 Dev=15.5 A.P.D= 2.5 Dev=1.3 C.P.U=266	S.L.= 38.3 Dev=14.3 A.P.D= 2.0 Dev= 0.9 C.P.U=313

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Ditch Miles)

Dev = Standard Deviation about Mean Estimate

C.P.U = Cost Per Unit of Accomplishment (Dollars)

Average Manhours Per Day = 68

N of Observations = 9

6.16 Comparison of Results with Literature Review Values

There was a limited amount of service life and cost information available in the literature as explained in Chapter 3. The activities with service life estimates that can be compared with those obtained for Indiana are shallow patching, premix levelling, seal coat operations, sealing longitudinal cracks and joints, crack sealing and pipe replacement. There were only two activities with comparable unit costings; chip seal and sealing cracks. The results for Indiana are tabulated with the other estimates for comparison purposes in Table 19.

6.16.1 Shallow Patching - Service Life

It can be readily seen from Table 19 that the range of service life estimates obtained for hot mix patches in Indiana is much wider than the estimated range in Ontario [13]. The main explanation for this is that the minimum estimates for Indiana on a poor road are extremely low because of the definition of failure used. As explained in section 6.3, failure is deemed to have taken place when the patched location needs to be treated again. On a poor road, this will be only a few months as the road itself will break up around the edge of the patch. Thus, although the hot mix material itself may not be in need of repair, the patched location will be. This failure concept may not have been used in Ontario.

The cold mix patch values for Indiana are generally lower than estimates obtained elsewhere. The maintenance crews are generally not happy with the quality of the cold mix in Indiana. It is interesting to note that the range for winter mix patches is from 1.0 to 6.8 months and is from 1.3 months to 24.1 months for Portapatcher patches. Thus, while the Indiana cold mix service life estimates do not compare well with other service life estimates, its other winter patching materials do compare well.

6.16.2 Premix Levelling - Service Life

The Indiana premix levelling values shown in Table 19 are certainly in the same general area as the Ontario estimates. The overall range is wider, but this is to be expected as the Ontario estimates, in common with most other published estimates are average values while the Indiana low estimate is for a minimum service life on a poor road.

6.16.3 Chip Seal - Service Life

Again in the case of a chip seal operation, the estimates obtained in this survey are comparable in magnitude with published estimates as can be seen in Table 19. The range for the Indiana estimates is slightly narrower than the range given by Darter and Shahin [27], while the Ontario range of only 6 months seems to be perhaps too narrow to take into account all of the factors that can affect an

actual chip seal service life in the field.

6.16.4 Sand Seal - Service Life

The Indiana service life estimates for a sand seal are lower than the Ontario estimates shown in Table 19 although there is a fair amount of overlap in the ranges given. As explained in Section 6.6.2, the maintenance personnel generally felt that sand seals were not as effective as chip seals in treating roadway deficiencies so the lower service life estimates may reflect that dissatisfaction.

6.16.5 Sealing Cracks and Joints - Service Life

Examination of Table 19 shows that the Indiana service life estimates obtained for Activity 206, Sealing Longitudinal Cracks and Joints, are generally slightly lower than the published estimates found in the literature review while the service life estimates for crack sealing (207) are generally of the same magnitude as those in the relevant literature. The reason for this, as outlined more fully in Section 3.5.4 of this thesis, is basically because the activity described as "sealing" in Indiana is generally considered to be crack "filling" elsewhere.

True joint-sealing usually is a more expensive and time-consuming procedure than joint or crack filling. The materials used in sealing are generally of higher quality

and this is reflected in the higher service life estimates contained in the "other" column of Table 19. In fact, when similiar materials and techniques are compared, as in Crack Sealing (207), it can be seen that the Indiana estimates contained herein are comparable to other estimates.

6.16.6 Pipe Replacement - Service Life

The estimates obtained for drainage pipe service life in Indiana appear to be lower than that recommended in NCHRP Synthesis #50 [19] as Table 19 shows. However, the difference is not really very significant as the Indiana values are gross estimates in the order of 15 to 20 years. There is not a great body of knowledge built up on the longevity of pipes as most of the foremen interviewed could not recall ever having to replace a worn-out pipe that they had laid. The NCHRP values are design values that should be aimed at so naturally it would be expected that these values would be high.

6.16.7 Chip Seal - Cost Estimates

The cost estimates outlined earlier in Chapter 3 and shown in Table 19 are the costs given by various states for laying one square yard of chip seal. The Indiana accomplishment unit is in lane-miles so a lane width must be assumed to convert this cost into a cost per square yard. A ten foot lane was assumed, and this gave a cost

estimate of $0.24 per square yard.

This value seems to be lower than the cost in other states, but the methods of computing cost may vary from state to state. Indiana does not include the cost of preparing the road for a chip seal in its chip seal costs which may explain its lower unit cost.

6.16.8 Crack Sealing - Cost Estimates

The cost estimates shown in Table 19 for this activity are in terms of total cost per gallon of sealing material used. The accomplishment unit in Indiana for sealing cracks is a lane-mile. However, earlier work in Indiana [34] indicated that approximately 100 gallons of sealant is used per lane mile. On this basis, the average cost per gallon for a poor road and a fair road were calculated and it can be seen that these values are comparable with estimates obtained from other sources.

Table 19
Average Service Life and Cost Estimates

AVERAGE SERVICE LIFE ESTIMATES (MONTHS)			
Activity	Indiana	Ontario [13]	Other
Shallow Patching (201)			
Hot Mix	3-55	36-48	-
Cold Mix	0.2-1.2	6-12	1-24 [28]
Premix Levelling (203) Hot Mix	18-48	36-48	-
Seal Coat (205)			
Chip Seal	24-55	30-36	12-60 [27]
Sand Seal	14-29	24-36	-
Sealing Long. Cracks and Joints (206)	17-38	36	40 [5] 40-60 [18] 36-72 [17]
Crack Sealing (207)	8-32	12 12-24 [28]	12-24 [17]
Pipe Replacement	180-240	-	300-480 [19]

AVERAGE COST ESTIMATES		
Activity	Indiana	Other
Seal Coat (per Sq. Yd.)	\$0.28	\$0.58 (Calif) \$0.23 (Louisiana) \$0.45 (Florida) \$0.31 (Nevada) \$0.44 (N. Dakota) [33]
Sealing Cracks (per Gallon)	\$5.08 (poor road) \$3.08 (fair road)	\$8.43 (Calif.) \$2.34 (N. Dakota) \$6.14 (Nevada) \$6.36 (N. Jersey) [33]

CHAPTER 7

ESTABLISHMENT OF PRIORITIES

The most cost-effective treatment for any given project location can be selected on the basis of the service life and associated cost data obtained in the present research. Consequently, the best use of resources is obtained for a given location. However, it is almost certain that there will not be sufficient funds available to perform the recommended treatment at all of the locations considered. Consequently, there is also a need to produce a priority ranking, at network level, to determine the optimal use of limited resources.

This is the same approach taken in Pavement Management Systems [21]. In the case of PMS, the primary factors considered in setting priorities are present condition, rate of change of condition, costs, traffic volumes and loads and minimum acceptable performance level [20]. However, the establishment of priorities within routine maintenance becomes more difficult as it is not just concerned with pavement activities [20,22]. Routine maintenance encompasses many diverse activities, each of which may have widely differing consequences.

The problem is reduced somewhat in the present case as only pavement, shoulder and drainage activities are considered. Nevertheless, these activities do have differing effects in terms of safety, energy, liability and other considerations as will be outlined later. Therefore it is essential that management establishes a weighting system for all of the activities considered so that a systematic allocation of resources can be made to match the goals and objectives of the IDOH maintenance management program.

7.1 The Need for Priority Ordering

The need for an order of priority in routine maintenance management must be explicitly stated so that the subjectivity involved in assigning these priorities can be minimized. The need exists primarily for the following reasons;

1. More resources are required to perform all necessary activities than are available.

2. All problems cannot be solved simultaneously.

3. All activities are not equally important in terms of their possible consequences.

4. Management needs to be able to manipulate and emphasize certain activities over others to produce an optimal use of funds.

The first factor above is an ever-present problem in all fields but is particularly relevant to routine maintenance at this point in time. It has been already pointed out that routine maintenance does not receive matching Federal funds and hence is completely dependent on State-generated funds. Consequently, there may a tendency to try to minimize these types of activities and an imbalance between desired remedies and realistic remedies inevitably develops. The work performed in this research allows an estimation to be made of the overall resources required as detailed cost information can be matched with the condition information obtained by the unit foremen. Thus, the shortfall in required resources can be identified on the basis of actual network condition, something that is not currently possible to do.

In considering the second reason for priority ordering, it must be realized that certain activities are, by their very nature, dependent upon the climate. Surface dressing and crack filling are two that fall within this category. Activities such as these will require a very high priority when allocating funds for a particular season and a very low or zero priority for other seasons. Because of this, it is necessary to have the cost information contained in this resaearch so that budgetary needs and allocations can be calculated on a seasonal basis. Thus, if management wants to emphasize crack

sealing, for example, it can calculate how much will be required in a particular season rather than on an annual basis and can make adjustments in expenditure through the year as a consequence of having this knowledge.

A high degree of subjectivity and engineering judgment must be applied in evaluating the consequences of prioritizing routine maintenance activities. Unquestionably, all activities do not have the same effect or consequences. For example, seal coating may have a much more beneficial effect in terms of road user costs than pothole repair, but conversely pothole repair may be more beneficial in terms of overall user safety. The balancing of diverse and conflicting interests among many dissimiliar activities is the main function of management and must be reflected in the proposed Routine Maintenance Management System. The cost-effectiveness of treatments will be obviously a very important factor to consider in assigning weighting priorities to different activities.

7.2 Establishment of Weighting Factors

The following significant factors have been identified [23] as being among the most important to be considered in weighting priorities.

1. Public Safety and Interest

2. Economics

3. Energy

4. Social and Environmental Concerns

5. Liability

6. Material Availability

7. Federal regulations

The particular effect of deferring an activity on all of these factors must be evaluated by management in Indiana itself. The service life and costs information obtained in this research will be very useful in clarifying the economics factor. Such consideration should lead to a weighting-factor system whereby a prioritization procedure can be carried out.

7.2.1 AASHTO Priority Factors

Studies to assign specific, numerical weights to different factors have already been carried out in several states and would be of interest in formulating specific values for Indiana. Also very relevant is a report based on the findings of an AASHTO committee that considered the whole problem of ranking activities and arrived at a list of 19 specific maintenance activities ranked in order of decreasing priority [6,7]. These were, briefly

1. Elimination of hazards or other conditions leading to road closure (heavy snowfall, blowups etc.)

2. Removal of hazardous objects in roadway

3. Repair of damaged or structurally inadequate structures

4. Repair of hazardous pavement conditions (bumps, holes etc.)

5. Replacement or repair of damaged, obscured, or missing signs, signals, markings and lighting

6. Correction of pavement dropoff at shoulders

7. Repair of damaged guardrail, traffic barriers and other off-roadway safety features

8. Repair of non-hazardous pavement deficiencies including overlays to preserve capital investment

9. Maintenance of drainage features

10. Minimal landscape maintenance to keep plants alive

11. Maintenance and minor repair of signing and signals

12. Maintenance and minor repair of structures

13. Safety rest area maintenance

14. Mowing to maintain adequate sight distance, prevent erosion and maintain drainage

15. Routine maintenance of roadside features

16. Provision of motorist aid patrols

17. Roadside cleanup

18. Mowing and other work for aesthetic purposes

19. Work for other agencies

7.2.2 Current Priority Weighting in Indiana

There is a general type of priority ranking currently in use in routine maintenance work in Indiana which also would be very useful in formulating the priority weightings [7]. The system as it stands has all activities classed as belonging to one of three possible categories, (1) Limited, (2) Unlimited and (3) Variable.

Unlimited activites are required to be performed when needed and in the amounts necessary to correct the deficiency. The justification for these activities being unlimited is that they are performed to maintain safe highways. Limited activities are defined as activities for which quantities can be established and firmly adhered to. An example of this would be Machine Mowing where the requirement is set at two or three cycles per year.

Variable activities are defined by the Procedures Manual as those activities for which the planned amount of work is not urgently needed each year. It is further stated that the planned work is desirable but it is not

critical if not completed during any one year. From these definitions, it is obvious that unlimited activities will have the highest priority weightings under any new system. Due to the nature of the systems manual, this threefold breakdown functions satisfactorily within the existing maintenance system in Indiana. A detailed inter-activity prioritization would serve no useful function in the present system and indeed would probably serve as a point of confusion.

However, in the proposed RMMS, management could indeed set priorities within each sub-group. At network level, the operation will consist of handling the accumulated data and transforming it into useful information. There will be very little additional work involved from the data handling viewpoint if detailed weighting functions are used. The benefit to routine maintenance management of being able to decide priorities on an activity basis far outweighs the extra effort that will be required to set up the program initially. As outlined earlier in this chapter, an economic evaluation of the effects of each activity would be very useful in determining the weights to be applied to each activity. The service life and associated costs data obtained in this research can be used within this economic evaluation and should be of major value in helping to set priorities for each activity within the current overall headings of

unlimited, limited and variable activities.

7.3 Chapter Summary

The development of a useable management program that gives useful results must inevitably include complex tradeoffs and hard decisions. In making these decisions, the program must remain close to the present system and reflect the goals and strategies of management at all levels. The advantage that a management program offers is a comprehensive and systematic decision-making process. It is also important to point out that the priority rankings chosen can change with time or with change in management strategy without affecting the mechanistic operation of the overall program structure in any way.

It is only through the use of a systematic procedure that the best overall use of available funds can be obtained. Among the primary functions of maintenance management in Indiana is to know and define what exactly the "best" is. The establishment of priorities and weighting values is a necessary step towards this definition. It is believed that the cost-effectiveness of various activities should play a large part in the determination of such a priority scheme. Consequently, the information contained in this research will be of use to management in Indiana in determining its own ranking of priorities and thus the best use of resources possible.

CHAPTER 8

SUMMARY AND CONCLUSIONS

The existing routine maintenance management of the Indiana Department of Highways was examined and it was found that, while the structure is adequate for present requirements and purposes, a need exists to obtain more consistency in treatment of maintenance deficiencies. This need must be met through use of a systematic approach to deficiency identification and subsequent treatment recommendation. The approach proposed should use unit foremen as the primary data collectors and implementors and should deviate as little as possible from existing management structures and procedures.

An examination of current research literature showed that most of the research to date has been in the field of major, rather than routine, maintenance. The various approaches taken to data collection for Pavement Management Systems were examined, and it was concluded that none of these approaches were directly applicable to routine maintenance data collection. Study of the limited published research specific to routine maintenance resulted in the conclusion that the approach to deficiency

identification and treatment taken by Ontario had the most applicability to the proposed RMMS in Indiana, given the existing maintenance structure in the IDOH. An examination of the available literature also showed that there was very little detailed routine maintenance service life or cost information available. The information that was available was not specific enough for use in a management program and was not directly applicable to Indiana for climatic, material quality and other reasons.

After consultation with experienced personnel, it became clear that there is almost always one prefered treatment for any particular deficiency in the routine maintenance field. This is in contrast to the major maintenance area, where a number of alternative treatments are usually possible. Consequently, the nature of the data collected for a routine maintenance program can be much less detailed than for the major maintenance case, but needs to be collected at relatively short intervals. The use of unit foremen as data collectors makes it possible to meet both of these criteria.

Effective service life and costs of all routine maintenance alternatives are essential parameters that must be determined for use in any management system that is intended to optimize the return per dollar invested. These parameters were obtained through a survey, based on random stratified sampling, of maintenance personnel at

the subdistrict level within Indiana. The cost and service life information gathered can be related to the condition information gathered by the unit foremen so that detailed cost estimates can be made of the resources required to correct the deficiencies as well as in identifying the most cost-effective treatment for a particular location. The range of activities covered encompassed the general areas of pavement, shoulder and drainage routine maintenance activities. However, there is no reason why the management system should be confined to these areas; as the proposed program comes into operation, its scope can be easily broadened to include other activities if so desired.

The task of assigning specific weights and priorities to various activities is one that must be completed by management in order to define and obtain the most suitable optimal solution for routine maintenance fund allocation in Indiana. The reasons why prioritization must be performed were outlined as well as some current recommendations and approaches to successfully producing appropriate priority selections. The service life and associated cost information contained herein will be extremely valuable to management in deciding upon the weighting values to be used. It was established that there already is a basic prioritization system in operation in Indiana and it is believed that the

broadening of this base to differentiate between specific activities can be carried out relatively easily.

The service life and associated costs obtained in this thesis provide a first, meaningful estimate of the necessary parameters to use as an aid to routine maintenance managers in Indiana. The next step that must be taken is to combine these parameters with the information currently being obtained on actual measurement of deficiencies in the field. When these are combined, the cost-effectiveness of maintenance treatments for any given deficiency can be computed. The unit foremen's condition reports will supply comprehensive information on the state of Indiana's roadways and roadway environment. The method of prioritization adopted will allow an optimal benefit to be accrued by the IDOH in its consideration and treatment of these condition deficiencies. The proposed data collection procedure is structured to function successfully at unit foreman level and its subsequent analysis will also yield invaluable network-level data. It should be a most useful tool to aid in the management of routine maintenance at all levels of the IDOH management structure.

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Appendix A

Typical Survey Form

ROUTINE MAINTENANCE ACTIVITY				
	Effective Service Life			
Roadway Condition	Minimum	Average	Maximum	*Average*
Poor	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D
Fair	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D
Good	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D	S.L. A.P.D

S.L. = Service Life (Months)

A.P.D = Accomplishments Per Day (Production Units)

Average Manhours Per Day =

Appendix B

Table B1. F-Values for Roadway Activities

Activity	Roadway Condition	F-Value S.L.	F-Value A.P.D.	F*-Value 50	90	95
Hot Mix Patch	Poor	0.26	3.65	0.77	3.26	4.74
	Fair	0.62	0.44	0.77	3.26	4.74
	Good	0.50	0.0	0.77	3.26	4.74
Cold Mix Patch	Poor	0.50	5.7	0.76	3.11	4.46
	Fair	2.0	0.05	0.76	3.11	4.46
	Good	4.0	0.25	0.76	3.11	4.46
Winter Mix Patch	Poor	0.60	6.50	0.77	3.26	4.74
	Fair	0.25	0.20	0.77	3.26	4.74
	Good	0.30	0.70	0.77	3.26	4.74
Portapatcher Patch	Poor	0.61	0.50	0.88	5.46	9.55
	Fair	0.70	0.83	0.88	5.46	9.55
	Good	1.18	1.40	0.88	5.46	9.55
Premix Levelling	Poor	11.90	1.85	0.55	4.32	6.94
	Fair	3.66	0.80	0.55	4.32	6.94
	Good	6.43	0.78	0.55	4.32	6.94
Shoulder Seal	Fair	0.57	1.24	0.77	3.26	4.74
	Good	0.59	1.20	0.77	3.26	4.74
Chip Seal	Poor	0.70	0.02	0.77	3.26	4.74
	Fair	0.38	0.21	0.77	3.26	4.74
	Good	0.70	0.22	0.77	3.26	4.74
Sand Seal	Fair	0.95	1.80	1.0	9.0	19.0
	Good	6.8	1.8	1.0	9.0	19.0
Long. Cracks And Joints	Poor	0.12	1.45	0.76	3.11	4.46
	Fair	0.19	2.45	0.76	3.11	4.46
	Good	2.0	3.2	0.76	3.11	4.46
Sealing Cracks	Poor	3.78	2.15	0.76	3.11	4.46
	Fair	0.19	2.45	0.76	3.11	4.46
	Good	0.18	1.19	0.76	3.11	4.46

Table B2
F-Values for Other Activities

Activity	Condition	F-Value S.L.	F-Value A.P.D.	F*-Value 50	90	95
Spot Repair of Shoulders	Poor	1.36	0.91	0.76	3.11	4.46
	Fair	0.22	0.60	0.76	3.11	4.46
Blading Shoulders	Poor	1.84	1.00	0.76	3.11	4.46
	Fair	0.28	0.02	0.76	3.11	4.46
Clipping Shoulders	Poor	4.19	3.22	0.76	3.11	4.46
	Fair	4.02	3.21	0.76	3.11	4.46
Recondition Shoulders	Poor	0.72	0.24	0.88	5.46	9.55
	Fair	18.40	5.50	0.88	5.46	9.55
Clean, Reshape Ditches	Poor	3.09	3.38	0.76	3.11	4.46
	Fair	3.46	5.32	0.76	3.11	4.46
Pipe Replacement	Small	0.99	0.00	0.76	3.11	4.46
	Medium	1.0	1.0	0.76	3.11	4.46
	Large	0.0	0.02	0.76	3.11	4.46
Motor Patrol Ditching	Poor	0.02	3.33	0.80	3.78	5.79
	Fair	0.55	1.65	0.80	3.78	5.79

Appendix C
Table C1
1985 -1986 Unit Costs

1985-1986 UNIT COSTS BY ACTIVITY			
Activity Number	Total Cost (Dollars)	Total Units	Cost per Unit (Dollars)
201	3,318,822	29,068	$114.17
203	492,576	11,880	$41.46
204	1,066,464	6,008	$177.50
205	1,976,209	1,464	$1352.60
206	305,583	2,816	$108.50
207	2,047,324	7,059	$290
210	919,886	67,440	$13.64
211	214,034	15,585	$13.73
212	389,340	1,895	$205.50
213	609,076	688	$885.60
231	1,259,696	2,067,100	$0.61
233	546,091	379	$1440.90
234	110,682	293	$377.80

Table C2
Average Labor Cost by Activity

AVERAGE LABOR COST BY ACTIVITY				
Activity Number	Total Labor Cost (Dollars)	Total Manhours	Avg. Daily Manhours	Avg. Labor Cost per Day
201	2,163,200	319,488	50	$338.5
203	122,760	17,424	88	$620.0
204	154,147	21,280	155	$1122.8
205	230,580	31,752	168	$1220.0
206	144,838	22,416	72	$465.2
207	1,280,032	188,240	88	$598.4
210	547,950	80,928	48	$325.0
211	180,786	24,936	24	$174.0
212	285,516	39,552	66	$476.4
213	162,890	22,912	130	$924.2
231	823,728	117,376	58	$407.0
233	169,034	24,256	63	$439.0
234	88,308	12,672	68	$473.9

Table C3
Variable Unit Costs by Activity

VARIABLE UNIT COSTS BY ACTIVITY			
Activity Number	(Total Cost-Labor Cost) (Dollars)	Total Units	Variable Cost per Unit
201	1,115,622	29,068	$39.76
203	369,816	11,880	$31.13
204	912,317	6,008	$151.85
205	1,745,629	1,464	$1192.4
206	160,745	2,816	$57.08
207	767,292	7,059	$108.70
210	371,936	67,440	$5.52
211	33,248	15,585	$2.13
212	103,824	1,895	$54.79
213	446,186	688	$648.53
231	435,968	2,067,100	$0.21
233	377,057	379	$994.90
234	22,374	293	$76.36

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